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Radioactive Contamination at
Nuclear Fuel Cycle Facilities

Rogers and Associates Engineering Corp.
Salt Lake City, UT

Prepared for

Environmental Protection Agency
Washington, DC

1982



U.S. Department of Commerce
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RADIOACTIVE CONTAMINATION AT NUCLEAR FUEL CYCLE FACILITIES

DECEMBER 1982

Prepared For:

**U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C.**

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ABSTRACT

This report presents information to characterize uranium fuel cycle facilities (excluding reactors), levels of contamination at those facilities, and volumes and activity of wastes associated with their decontamination and decommissioning (D&D). It is one of a series of reports providing information to assist the U.S. Environmental Protection Agency in setting standards and guidelines for permissible residual levels of radioactivity from D&D.

The categories of facilities covered by this report are:

- Uranium mines
- Uranium mills
- Uranium hexafluoride conversion plants
- Uranium enrichment plants
- Fuel fabrication plants, including both low and high enriched uranium and mixed oxide facilities
- Fuel reprocessing plants

Both active and inactive facilities are identified. Although emphasis is placed on the light water reactor fuel cycle, other facilities (e.g., high enrichment fuel fabrication plants and Department of Energy conversion and fuel fabrication plants) are also identified. The technical assessments and associated estimates of D&D wastes are based on information in the open literature. Engineering judgement has been used where necessary.

The highest volumes of D&D waste (hundreds of millions of cubic meters) are associated with uranium mines, while the highest amounts of radioactivity are a result of D&D at fuel reprocessing plants.

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1. INTRODUCTION

1.1 PURPOSE

The U.S. Environmental Protection Agency (EPA) is developing a series of environmental protection standards governing the disposal of radioactive wastes. Related to these standards is the need for federal radiation protection guidance on residual radioactivity for use in planning and implementing decontamination and decommissioning decontamination and decommissioning (D&D) at nuclear sites, and facilities.

In order to properly develop guidance for residual radioactivity, technical assessments are required to characterize the problem, evaluate the risks, examine available D&D methods (including their costs), evaluate occupational risks for these methods, analyze techniques for demonstrating compliance, and review and summarize existing standards and regulations related to D&D. This report is one in a series of reports being prepared for EPA to characterize anticipated waste volumes from D&D of contaminated facilities.

The current series of reports characterizes contaminated sites, facilities, and materials that may eventually require D&D. Information is provided on the types and numbers of contaminated nuclear sites, facilities and materials requiring decommissioning, whether sites are active or inactive, and, if active, the expected remaining operating life. Information is also given on the quantity and concentration of the radioactivity making up the contamination, with special emphasis on long-lived materials. This information includes descriptions of salient chemical and physical characteristics of contamination, when available, and estimates of

the volumes and nature of radioactive waste which would be produced during decontamination activities.

The EPA has categorized the radioactively contaminated sites, facilities and materials into the following seven groupings:

- I. Nuclear power reactor sites and facilities (both Light Water Reactors and High Temperature Gas-Cooled Reactors).
- II. Nuclear fuel cycle facilities other than reactors (mines, mills, conversion and enrichment plants, fuel fabrication facilities, fuel reprocessing and fuel storage facilities, and mixed-oxide fuel fabrication plants).
- III. Research, test, university and isotope production reactor sites and facilities.
- IV. All Federally-owned sites and facilities, or those for which the government has responsibility, which have radioactive materials or wastes, including U.S. Department of Energy (DOE), national laboratories and sites included in remedial action programs.
- V. Radioisotope and radiopharmaceutical manufacturers and suppliers licensed by the U.S. Nuclear Regulatory Commission (NRC) or the states.
- VI. Independent research and development laboratories or institutions, including those currently licensed, licensed in the past, and those not licensed. Accelerators are to be included in this group.
- VII. All radioactive waste sites, excluding high-level waste repositories and uranium mill tailings repositories (subject to Public Law 95-604, "Uranium Mill Tailings Radiation Control Act of 1978"), regardless of ownership: government, commercial or abandoned.

The EPA has decided that sufficient information is available for Categories I, III, and VII and that additional reports will not be prepared at this time.

1.2 SCOPE AND OBJECTIVE OF THIS REPORT

This report covers the Category II facilities--nuclear fuel cycle facilities other than reactors. This category includes uranium mines, mills, conversion, enrichment, and fuel fabrication facilities; away-from-reactor fuel storage; fuel reprocessing; and mixed-oxide fuel fabrication facilities. There is some overlap of this report with the parallel report on federal facilities (Be82), since the uranium enrichment plants are DOE facilities. The inactive uranium mills are part of the U.S. Department of Energy (DOE) remedial action program (DOE80) and are also included in Be82. By-product recovery of uranium from the phosphate industry and other mineral industries are covered in this report.

This report identifies and characterizes the fuel cycle facilities, many of which are licensed by the U.S. Nuclear Regulatory Commission (NRC), and provides estimates of the existing contamination and projections of radioactive wastes from D&D of the facilities. This includes:

- Radionuclides making up the contamination, including quantities in curies (kilograms for uranium), concentrations in specific activity, or contamination in terms of unit volume or area.
- Physical and chemical descriptions of the contamination.
- Estimates of the volumes and characteristics of waste produced by D&D using currently available technology.
- Descriptions of items contaminated with radionuclides with half-lives greater than 30 years.
- Status of each facility, whether it is active or inactive, and, if active, the expected remaining operating life, and the operating life for generic facilities.
- Available information on materials which may be suitable for recycle.

1.3 ORGANIZATION OF THE REPORT

Because of the broad spectrum of facilities in the fuel cycle each category of facility is treated in a separate chapter. For several categories of facilities (i.e., mines, mills and fuel fabrication) the types of facilities are subdivided into separate sections. The organization of the facilities by chapter are in the sequence of material flow through the fuel cycle; i.e., mines are treated first.

Chapter 2 describes the methodology used in performing the technical assessments reported in this document, including a brief description of the general approach and basic assumptions used in developing this document. Subsequent chapters assess the various facilities.

Uranium mines are assessed in Chapter 3. Categories of active and inactive open-pit and underground mines are used. In-situ or solution mining, heap-leach operations, and by-product recovery of uranium from other minerals are included in Chapter 4 with conventional uranium mills. The primary process operations from these additional uranium recovery techniques are similar to milling processes.

Uranium hexafluoride conversion facilities are treated in Chapter 5. There are only two operating plants, but there are several inactive DOE plants.

The DOE uranium enrichment facilities are covered in Chapter 6. The evaluations are limited to the three gaseous diffusion plants since the centrifuge plant is still under construction and not scheduled for initial start-up until 1985 and full operation until the late 1980s (DOE81c).

Fuel fabrication is covered in Chapter 7. Separate sections are given

for uranium fuel fabrication and fabrication of mixed oxide fuels (uranium and plutonium).

Chapter 8 presents a characterization of fuel reprocessing facilities and away from reactor irradiated fuel storage. Primary emphasis is given to the West Valley, New York, site, the only commercial fuel reprocessing plant that has been operated in the U.S.

Reference facilities have been developed for most of the types of fuel cycle facilities. The reference facilities include several types of mines, uranium mills, uranium conversion plants and both uranium and mixed oxide fuel fabrication plants. Estimates of existing contamination and D&D wastes for the actual facilities are then scaled from the reference facilities. Each fuel reprocessing plant was considered separately, without developing a reference facility. Because of the minimal information available on enrichment plants, estimates were obtained by scaling from the reference uranium fuel fabrication facility.

2. METHODOLOGY

This chapter contains a brief description of the methodology used in performing the technical assessment of uranium fuel cycle facilities.

2.1 APPROACH

The general approach used in this assessment was to identify and compile available information on the pertinent facilities, and to exercise engineering judgement in extrapolating available information to form estimates of waste types and quantities where no information could be found. Detailed references to available information are provided to facilitate further studies and evaluations.

Studies have been funded and reports published on the technology and costs of D&D at nuclear facilities (e.g., El80, El81, Je79, Ma80, Mu80, Sc77, Se77, Sk78). Furthermore, studies have been conducted to characterize mines, mills, and other facilities (EPA82, Ja80, Ni79, Th82, NRC80, NRC81). Also, formal D&D activities, such as the DOE remedial action programs (UMTRAP, FUSRAP, etc), have received funding for many years and good estimates of waste characteristics and volumes are available from several sources (DOE80, DOE80b, DOE81, DOE82a). Existing documents and information were used when possible. Cross checks between documents were also made.

For most categories of facilities, a reference facility was defined and estimates of wastes were derived for the reference facility. Those estimates were then scaled according to capacity, area, volume, etc., to

generate estimates for existing facilities. In all cases a special effort was made to identify all of the facilities.

2.2 LITERATURE REVIEW

The scope of this technical assessment is limited to the use of existing information. Therefore a thorough review of available literature provides the basis for information presented in this report. In performing the literature review, the published bibliographies on D&D topics were examined (e.g., Fa80, Ko78), and data bases were searched. Library facilities at the University of Utah (a DOE Repository Library), the Idaho National Engineering Laboratory (INEL) and Battelle Pacific Northwest Laboratory (BPNL) were used. The data bases searched included:

RECON (DOE's data base of Government reports)

SCISEARCH

DIALOG

BRS (DOE Energy Database)

ORBIT

Over 50,000 references to radioactive waste are contained in these data bases. The references were narrowed down to manageable numbers by using carefully selected key words. For instance, "Decontamination", "Fuel Reprocessing", and "Waste" together yielded 115 references in the BRS search. The key words, used separately or in various combinations, were: Radioactive Waste, Enrichment, Conversion, Fuel Storage, Mixed Oxide Fuel, Fuel Reprocessing, Inventories, Decontaminate, Decontamination, Isotope

Separation, Gaseous Diffusion, Excess Contaminated Facility, Fuel Fabrication, Decommission, Nuclear Waste, Decommissioning Waste, Reprocessing Waste, Uranium Mines, Uranium Mills, Uranium Mill Tailings, Low-Level Waste, and Remedial Action Program.

The references obtained from the bibliographies and searches using combinations of the above keywords were then screened to select the most promising titles for further study. Copies of documents were obtained and reviewed to obtain further useful references. The reviewed references also provided names of cognizant individuals who were sometimes contacted for further detailed information.

2.3 OTHER SOURCES OF INFORMATION

As mentioned above, personal communications were made with individuals known by the authors to be involved in work on D&D of radioactive facilities. In addition to providing help in identifying and obtaining useful documents, these contacts often revealed information that is not available in existing reports--either because it has never been published or because values, assumptions, etc., have changed since the most recent reports were prepared. The use of personal communications has helped to improve the accuracy of this assessment.

2.4 ASSUMPTIONS FOR DECONTAMINATION AND DECOMMISSIONING

For most of the existing contaminated sites, facilities or materials, some information is available concerning the present status. However,

there are many facilities now in use for which D&D plans have not been formalized; in some instances, little information is available on present radioactive inventories or inventories projected to the time of that facility's decommissioning. For some types of facilities there is past experience in D&D, while for others no D&D activities have been attempted. Also, the type of D&D activity to be used at many specific locations has not been decided. For these reasons, there is considerable uncertainty in the estimates presented in this report. However, an effort has been made to present the information on a consistent basis, and to explain the assumptions used in estimating waste volumes and types.

2.4.1 Alternatives

There are many possible choices of decontamination methods and degrees of cleanup to be accomplished, as well as many possible options for final site decommissioning. Throughout this report, the term "D&D" is used to mean those activities taken at a contaminated site or facility to prepare it for its projected disposal or release for unrestricted use. Because of the long half lives (thousands of years) of most of the radionuclides involved for the subject facilities, the waste estimates are generally predicated on decontamination of facilities to allow their unrestricted use. In most instances, it is assumed that structural facilities are left in place for future use. The intent is not to prejudge the selection of D&D alternatives, but rather to attempt to assess the total amount of wastes from reasonable D&D efforts. Furthermore, an underlying philosophy of minimizing the number of long term waste repositories (areas with restricted use) has been used.

Since there has been some misunderstanding in the past about terminology used in the decommissioning field, the NRC has set forth standardized definitions of terms. These definitions have been adopted for use in this report, and are repeated verbatim here from Ca81:

"Some confusion and misunderstanding has resulted from the variation of terminology used in the decommissioning field. For example, the words decommission, decontaminate, and dismantle have been used interchangeably for the decommissioning alternative consisting of the immediate removal of all radioactive material to permit unrestricted release of the property. The word dismantlement has been used to describe decontamination activities that involve no actual dismantlement. Similarly, the words safe storage, protective storage, lay away, mothball, and temporary entombment have been used to name the alternative decommissioning consisting of placing and maintaining property safely in storage as a precursor to final decommissioning.

In the interest of ending the confusion it appears desirable to strictly define decommissioning and the major alternatives for accomplishing it. Furthermore the use of pseudoacronyms for the alternatives avoids words which have several meanings.

Definition of Decommissioning

Decommission means to remove the property safely from service and dispose of the radioactive materials. The level of any residual radioactivity on the property must be low enough to permit unrestricted release of the property.

Definitions of Decommissioning Alternatives

DECON means to immediately remove all radioactive material to permit unrestricted release of the property.

SAFSTOR means to fix and maintain property so that risk to safety is acceptable for a period of storage followed by decontamination and/or decay to an unrestricted level.

ENTOMB means to encase and maintain property in a strong and structurally long-lived material (e.g., concrete) to assure retention until radioactivity decays to an unrestricted level."

The above definitions and alternatives will be used in this report to

describe activities. Note that essentially all decommissioning activities at contaminated sites also involve decontamination. Hence, "D&D" will be used throughout this report. Of the three alternatives defined, the one that appears to be most feasible for a given facility will be used in making the estimates that follow.

DECON requires immediate expenditure of funds, but allows release of the site for uncontrolled use and saves the expense of continued security and surveillance. SAFSTOR delays the need for most expenditures and also allows for use of a standby status and possible reuse of the facility. However, for the long half life radionuclides that are of primary interest in this study, SAFSTOR will entail costs of surveillance and eventually the same efforts for DECON as immediate DECON. Furthermore, the staff that was familiar with the operation of the facility may be gone when the DECON finally takes place. It is difficult to envision the ENTOMB alternative being adequately implemented for most of these facilities, given the long half lives of the contaminating materials.

2.4.2 Criteria for Levels of Residual Activity

A number of criteria for guidance on allowable levels of radioactivity after D&D have been promulgated or proposed by federal agencies or standards organizations. They include the Surgeon General's Criteria used in the Grand Junction, Colorado, Remedial Action Program (PHS70, PL72); "Interim Cleanup Standards for Inactive Uranium Processing Sites" (EPA80); Draft American National Standard "Control of Radioactive Surface Contamination on Materials, Equipment, and Facilities to be Released for Uncontrolled Use" (ANSI78); "Proposed Federal Radiation Protection Guidance

For Persons Exposed to Transuranic Elements in the Environment" (EPA77); "NRC Regulations for Radiation Exposures" (NRC81c); and "Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source or, Special Nuclear Material" (NRC76a). The criteria for D&D are discussed in Co79, and Sh79 provides an analysis of current decommissioning regulations. The NRC has published a draft generic environmental impact statement on decommissioning of nuclear facilities (NRC81), and guidance on uranium mill D&D is provided in NRC80. NRC81b presents licensing requirements for land disposal of radioactive wastes. Many of the criteria are in draft form or are presented as guidance only, and some, such as the Grand Junction Guidance and Interim Cleanup Standard, are intended only for specific situations. Major remedial action programs such as UMTRAP are awaiting final standards before proceeding in earnest.

Several of the criteria can cover a wide range of nuclides. They are usually based on specific assumptions about future uses of the decontaminated buildings and land, and are related to assumed acceptable levels of exposure to individuals. Two criteria for radionuclides in soil are the EPA's recommendations of 0.2 microcuries/m² of transuranics in soil (surface contamination to a depth of one centimeter) (EPA77) and 5 pCi/g of radium-226 in the top 5 cm of soil (EPA80, EPA80a). The first figure can be translated into approximately 15 pCi/g of plutonium in soil.

While cleanup criteria may play a role in estimating the volumes of waste from D&D and concentrations of nuclides in that waste, information about existing radioactivity at facilities requiring cleanup is usually not available in sufficient detail to observe the effects of different standards.

3. URANIUM MINES

The uranium industry has undergone a series of transformations in the past 40 years. Uranium changed from a commodity of minor commercial interest to one vital for nuclear weapons and important for use as a fuel for electrical power generation. The military demand for uranium in the early 1940's had to be met from known sources of supply. Much of the uranium supply during this period came from the rich pitchblende ores of the Shinkolobwe deposit in the Belgian Congo and the Great Bear Lake Deposit in Canada. Uranium from these sources was supplemented by domestic supplies obtained by processing old tailings dumps from other mineral mining and a few small mines in the Colorado Plateau area (NRC80). Much of the early U.S. production of uranium was from ores mined for other purposes; e.g., vanadium and even radium.

Uranium mining and resource development is estimated to account for 40% of the production costs of uranium concentrates (U_3O_8) (De70). The two most common methods of uranium ore extraction are underground and surface mining. Together they produced about 90% of the uranium in 1979. In-situ solution mining is becoming more viable and was estimated to account for about 7% of production in 1979 (NRC80). Solution mining is a method of solubilizing the ore in the geological formation and removing it from the ground without the necessity of the typical mining earth-moving operations. When the solution is brought to the surface, it is in a condition comparable to an advanced stage of the milling process. It is therefore discussed in Chapter 4, on mills. Other minor extraction methods are also more similar to milling than mining, such as removing uranium as a

by-product from the waste of a phosphate production plant. These methods are also discussed in Chapter 4.

The particular mining method utilized is determined by cost factors which are influenced by the size, shape, depth, and thickness of the ore deposit (NRC80).

The average grade of mined ore has decreased with time as the richer formations are mined. The average grade for ore processed at the older inactive mill tailings sites ranged from 0.04 to 0.36% U_3O_8 * equivalent with nominal values around 0.25% (EPA80a). The average ore grade has decreased from 0.16% in 1977 to 0.13% and 0.12% in 1978 and 1979, respectively. It is projected that the average grade will decrease to about 0.08% by the year 2000 (NRC80).

DOE81a, published in January 1981, reported that there were 303 underground and 52 open-pit (surface) uranium mines in the U.S. There was also uranium production from 33 other sources. EPA82, using listings of mines on computer tapes from DOE (DOE79), the Department of Interior (DOI79), and the Department of Labor (DOL79), estimated that there was a total of 321 active mines. The computer tapes (DOE79 and DOI79) were current as of early 1979. The value of 321 was obtained after deleting double listings, very small mines, and mills.

* The uranium content of ore and uranium concentrate (often termed yellowcake) is generally stated as the weight percent, equivalent to U_3O_8 . That is, 100% indicates 100% U_3O_8 which is only 84.8% uranium. The specific activity for 100% ore (U_3O_8 equivalent) is 0.283 microcuries of U-238 per gram. The specific activity of 100% uranium is 0.334 microcuries of U-238 per gram (also 0.331 and 0.0154 microcuries of U-234 and U-235, respectively). The specific activity of 0.1% ore is 283 pCi of U-238 per gram (based on half-lives and isotope ratios from Wa77).

The large number of sites, the lack of specific and unique names, the lack of uniform and accurate location information (e.g., latitude and longitude), and the changing status of mines makes it difficult to obtain accurate listings of the mines. The information for inactive mines is much less accurate and more incomplete than that for active mines.

The active uranium mines in the U.S. are summarized by county and state in Table 3-1 (taken from EPA82). There are mines located in most of the western states. This table lists 348 locations, which include by-product recovery operations.

Table 3-2 shows the 1980 production of uranium ore by state. This includes all production, not just mining. These data show that 63 percent of the uranium production takes place in the states of New Mexico and Wyoming.

In 1980, uranium mines (conventional open-pit and underground) produced and delivered to mills and buying stations 15 million metric tons (MT) of ore containing 18,000 MT of U_3O_8 . Sixty-two percent of this was from open-pit production (DOE81a). Projections of future requirements of uranium by the nuclear power industry indicate that an annual production of about 36,500 MT of U_3O_8 will be needed by the year 2000 (NRC80).

Cummulative mine production through 1980 was about 172 million MT, 47 percent from surface mines and 53 percent from underground mines. This yielded about 331,000 MT of U_3O_8 , 41 percent from the surface ores and the rest from underground ores.

The lifetime of mines is dependent on the size of the ore body and the rate of mining, the location and grade of the ore body, market conditions, and the numerous parameters that affect the cost effectiveness of the

TABLE 3-1
SUMMARY OF THE ACTIVE URANIUM MINES IN THE UNITED STATES
Source: EPA82

<u>County</u>	<u>State</u>	<u>Total Mines</u>	<u>Surface</u>	<u>Underground</u>	<u>Other*</u>
Healy	Alaska	1	0	0	1
Talkeetna	Alaska	2	0	0	2
Pima	Arizona	1	1	0	0
Inyo	California	1	0	1	0
Kern	California	1	0	1	0
Custer	Colorado	1	1	0	0
Dolores	Colorado	2	0	1	1
Fremont	Colorado	2	0	1	1
Garfield	Colorado	2	0	1	1
Jefferson	Colorado	5	3	1	1
La Plata	Colorado	1	0	1	0
Mesa	Colorado	21	6	15	0
Moffat	Colorado	1	1	0	0
Montrose	Colorado	44	3	41	0
Ouray	Colorado	2	0	2	0
Park	Colorado	2	0	2	0
Rio Blanco	Colorado	1	0	1	0
San Miguel	Colorado	26	3	23	0
Hamilton	Florida	2		0	0
Hillsborough	Florida	3		0	0
Polk	Florida	20		0	0
Blaine	Idaho	1		0	0
Bonneville	Idaho	1		0	1
Caribou	Idaho	3		0	1
Carbon	Montana	1		0	0
Lincoln	Nevada	2		0	2
Washoe	Nevada	1		0	1
McKinley	New Mexico	38		34	2
Sandoval	New Mexico	1		1	0
Valencia	New Mexico	11		5	3
Beaufort	North Carolina	2		0	0

TABLE 3-1 (Continued)

<u>County</u>	<u>State</u>	<u>Total Mines</u>	<u>Surface</u>	<u>Underground</u>	<u>Other</u>
Custer	South Dakota	1	1	0	0
Fall River	South Dakota	6	6	0	0
Gonzales	Texas	1	1	0	0
Karnes	Texas	5	4	0	1
Live Oak	Texas	2	1	0	1
Garfield	Utah	2	0	2	0
Grand	Utah	5	0	4	1
Millard	Utah	1	0	1	0
San Juan	Utah	40	4	36	0
Washington	Utah	1	0	1	0
Wayne	Utah	2	0	1	1
Stevens	Washington	5	2	0	3
Campbell	Wyoming	1	0	0	1
Carbon	Wyoming	10	5	3	2
Converse	Wyoming	11	3	5	3
Fremont	Wyoming	44	28	10	6
Johnson	Wyoming	1	1	0	0
Nathona	Wyoming	7	4	0	3
Sweetwater	Wyoming	<u>1</u>	<u>0</u>	<u>0</u>	<u>1</u>
TOTAL		348	114	194	40

* Other includes prospecting and placer mines.

TABLE 3-2
DISTRIBUTION OF 1980 URANIUM PRODUCTION BY STATE
Source: DOE81a

<u>State</u>	<u>Production of U₃O₈ (10³ MT)</u>	<u>Percent Of Total</u>
New Mexico	7.5	35
Wyoming	5.8	28
Texas	3.2	15
Others: Arizona, Colorado, Florida, Louisiana, Utah, and Washington	<u>4.7</u>	<u>22</u>
TOTALS	21.2	100

operation. For example, if a nearby mill shuts down, the haulage distance may increase and operating a given mine may not be profitable. The average life for an open-pit mine is estimated to be 17 years (Ni79). The average life for underground mines is estimated to be 30 years (Ja80). The operating life of actual mines varies considerably from these estimates. Table 3-3 gives a summary of inactive mines by state. There are over 3000 inactive mines. Over 1200 of the inactive mines are in Colorado. Most of these inactive mines were small operations on the Colorado plateau in western Colorado. Many of these mines were abandoned with minimal, if any, reclamation. The numbers in the table differ slightly from the totals of 1246 surface mines and 2031 underground mines given by Ha81.

Table 3-4 indicates the distribution of active and inactive mines by the amount of ore produced (EPA82). It is evident that the active mines are generally fairly large, over 910 MT production, while most of the inactive mines have produced less than 91 MT.

There is very little information on official D&D programs for mines. Although some states (e.g., Wyoming) require reclaiming mine land, the requirements vary (EPA82). There is a trend in open-pit mining to backfill one pit with the subore and waste from the next pit, but there are no uniform official requirements. Several Federal agencies are working on developing programs.

Representative open-pit and underground active and inactive mines are developed in the next section.

TABLE 3-3
THE LOCATION AND TYPE OF INACTIVE URANIUM PROPERTIES
Source: EPA82

<u>State</u>	<u>Surface Mines</u>	<u>Underground Mines</u>	<u>Other</u>
Alaska	0	1	0
Arizona	135	189	2
California	13	10	0
Colorado	263	902	52
Florida	0	0	1
Idaho	2	4	0
Minnesota	0	0	1
Montana	9	9	0
Nevada	9	12	0
New Jersey	0	1	0
New Mexico	34	142	12
N. Dakota	13	0	0
Oklahoma	3	0	0
Oregon	2	1	0
S. Dakota	111	30	0
Texas	38	0	4
Utah	378	698	17
Washington	13	0	0
Wyoming	223	32	10
Unknown	<u>6</u>	<u>5</u>	<u>2</u>
TOTAL	1252	2036	101

TABLE 3-4
CUMULATIVE ORE PRODUCTION THROUGH JANUARY 1, 1979
Source: EPA82

Production (MT)	Active Mines				Inactive Mines			
	Number of Mines ^a	Percent of Total Mines	Surface	Under- Ground	Number of Mines ^a	Percent of Total Mines	Surface	Under- Ground
91	16	(4.7)	8	3	1553	(45.8)	899	628
91-910	33	(9.7)	5	24	753	(22.2)	134	588
910-91,000	188	(55.3)	15	165	986	(29.1)	180	766
91,000	<u>103</u>	<u>(30.3)</u>	<u>32</u>	<u>64</u>	<u>97</u>	<u>(2.9)</u>	<u>39</u>	<u>54</u>
TOTALS	340	(100.0)	60	256	3389	(100.0)	1252	2036

^a Includes all mines, not just surface and underground.

^b These figures differ slightly from the totals given by DOE81a.

3.1 REFERENCE URANIUM MINES

3.1.1 Description of Reference Mines

Uranium mining involves the movement of large quantities of uranium ore and non-ore material. Open-pit mining is used where deposits are shallow and the overburden is loosely consolidated soil. It is usually preferred for areas where there is less than 90 m of overburden, although it has been used in areas of greater overburden (De70). The areas of mineable ore deposits vary considerably. The areas for the larger mines range from about one-tenth to one square kilometer (Th82). Open pit mining usually is carried out by excavating a series of pits in sequence. The mining procedure followed is to remove the topsoil and overburden from above the ore zone and to stockpile these materials in separate piles for use in future reclamation operations. The uranium ore is removed from the exposed ore zone and stockpiled for transport to a uranium mill. Ore stockpiles range in size up to several hundred thousand metric tons of ore. During the mining of the uranium ore, low-grade waste rock is also removed from the pits and stored in a waste stockpile for possible future use.

Deeper ore deposits require underground mining. Specific methods used vary according to the specific geology. The main entry shaft can range from an inclined entry into a canyon wall to a large vertical shaft.

3.1.1.1 Open-Pit Mines

Nielson et al. (Ni79) report the results of a study of eight open-pit mines in Wyoming in 1978. An update of the study is given in Th82. Table 3-5 lists the average parameters for these mines based on the updated

TABLE 3-5

REFERENCE OPEN-PIT URANIUM MINE PARAMETERS: AVERAGE OF EIGHT MINES
Source: Th82

<u>Parameter</u>	<u>Reference Parameters</u>	
	<u>Average</u>	<u>Range</u>
Expected Mine Life (years)	17	4-30
Ore Production (MT/day)	1460	730-2700
Average Ore Grade (%U ₃ O ₈)	0.11	0.063-0.19
Average Cutoff Grade (%U ₃ O ₈)	0.03	0.015-0.05
Average Subore Grade (%U ₃ O ₈)	0.023	0.0075-0.042
Average Overburden Grade (%U ₃ O ₈)	0.0028	0.00066-0.015
Thickness of Overburden (meters)	63	18-84
Thickness of Ore Zone (meters)	20	0.3-61
Overburden to Ore Ratio	65	25-131
Subore to Ore Ratio	1.1	0.175-3
Number of Pits	19	3-71
Pit Wall Slope from Vertical (degrees)	39	14-57
Lifetime Volumes (assume 17 years and 286 days/year)		
Ore (10 ⁶ MT)	7.1	
Total Overburden (10 ⁶ MT)	460	
Total Subore (10 ⁶ MT)	7.8	
Overburden from 1 pit (10 ⁶ MT)	24	

study (Th82). These parameters are used to characterize the reference open-pit mine.

The basic differences between the Th82 reference parameters and the original Ni79 reference mine are the number of pits (19 versus 7), the subore grade (0.023% versus 0.015%), and the overburden uranium content (0.0028% versus 0.002%), respectively. The reference mine in EPA82, which is based on Ni79, estimates somewhat lower concentrations in waste materials than the reference mine of this report.

Although the reference values from Th82 characterize the sampled mines in Wyoming, which are generally representative of new and future mines, the present average mine is somewhat smaller (Table 3-4). Therefore, the values for actual mines will be scaled from the reference mine, based on the relative production rates.

The tendency for present-day and future open-pit mines is to place the overburden from new pits into old pits rather than on the surface (Ni79, Th82). For example, when a mine is started, the overburden for the first two pits is placed on the surface. The overburden from future pits is then placed in mined-out pits. In some cases the overburden from both of the first pits will be moved to pits. At other mines both piles will be left. Therefore, it is assumed, for the average case, that the overburden from one of the first two pits is also relocated to a pit.

The subore is all placed in a common pile on the surface for potential future processing. The cutoff grade is the minimum grade of ore sent to the mill. Therefore, the grade of the subore is the average of material below the cutoff grade and the grade of the overburden.

After the active mining period has ceased, the reference mine will

have 18 of the 19 pits filled with overburden. There will be a single overburden pile remaining, and all of the ore piles will have been removed, and a single subore pile (subore from 19 pits) is left in place. Totals of the materials for a 17-year operating period are given in Table 3-5 for both placing the overburden material in the pits or placing it all on the surface.

3.1.1.2 Underground Mines

Jackson et al. (Ja80) report the results from a survey of seven underground mines. The average underground uranium mine is a modified room-and-pillar mine with stopes in ore. After an area has been mined out, the earth above the rooms is allowed to cave in. The excavation is in dry to moderately wet, loosely consolidated, sandstone.

The waste removed from the mine is placed on the surface in a pile with a depth of 0.3 to 6 m. Table 3-6 shows the dimensions and other statistics determined for the seven mine waste piles and for projections to the end of life of the mine (assumed to be 30 years total life). The projections were based on the ratio of annual ore to waste production for the specific mine, or an average ratio of 7.3, based on the average production of ore and waste (1978) for the seven mines.

Three of the mine waste piles (Table 3-6) could not be extrapolated to end of lifetime because of insufficient data regarding current mine age or the current waste pile geometry.

Production statistics for six of the mines from Table 3-6 are given in Table 3-7. The average ore production is 570 MT/day, with a grade of 0.15%.

TABLE 3-6
PARAMETERS FOR SELECTED UNDERGROUND MINES
Source: Ja80

<u>Mine</u>	<u>Area of Mine Waste (10³m²)</u>	<u>Pile Height (m)</u>	<u>Grade (% U₃O₈)</u>	<u>Volume of Waste Pile (m³)</u>
<u>During Study</u>				
1	8.3	4.7	0.031	36,400
2	5.4	2.3	0.030	10,100
3	20	6.6	0.040	127,300
4	17	6.5	0.043	105,700
5	6.0	2.1	0.033	12,200
6	72	1.2	0.025 ^a	87,200 ^a
7	190	0.30	0.025 ^a	56,700 ^a
<u>At End Of Mine Life</u>				
1	56	6.6	0.031	354,000
2	^b	-	-	-
3	45	6.6	0.040	286,000
4	31	6.5	0.043	180,000
5	^b	-	-	-
6	143	3.5	0.025 ^a	497,000
7	^b	-	-	-
Average ^c	69		0.032	332,000

^a Estimated.

^b Insufficient data to project the wastes.

^c The averages are based on mines 1, 3, 4, and 6; except that the ore grade is based on the average of all seven.

TABLE 3-7
 PRODUCTION PARAMETERS OF UNDERGROUND MINES
 Source: Ja80

<u>Mine*</u>	<u>Age (Years)</u>	<u>Production (MT/day)</u>	<u>Grade (% U₃O₈)</u>
1	2	500	0.11
2	-	140	0.16
3	21	910	0.16
4	21	500	0.10
6	4	720	0.18
7	20	650	0.19
AVERAGE	-	570	0.15

* Numbers correspond to mines in Table 3-6.

The parameters for the reference underground mine are summarized in Table 3-8.

EPA82 presents parameters for a large and an average model mine. The production parameters for the two EPA mines, 700 MT/day and 59 MT/day for the large and small mines, respectively, generally bracket the reference mine except for assuming lower uranium content in the waste. The EPA82 mine assumes a 17-year lifetime and a rather high waste-to-ore production ratio of 1 (reference mine value is 0.14). The EPA82 models also assume a subore-to-ore production ratio of 1; whereas, the reference mine, based on Ja80, includes subore with the mine waste. The end result is that the waste estimates from the reference mine (570 MT/day ore production) are similar to those for the EPA82 average mine (59 MT/day ore production).

The parameters from Ja80 are used to define the reference mine since they are based on empirical results and reflect the average waste-to-ore ratios reported for underground uranium mines (DOE81a).

3.1.1.3 Inactive Uranium Mines

There is very minimal information available on inactive surface and underground uranium mines. EPA82 has compiled the available information on inactive underground and surface mines and developed models. The parameters for the EPA82 model mines are used to define the reference mines. The values are given in Table 3-9. The parameters for the reference active mines are also given in Table 3-9 to allow comparison of the values. The inactive mines are much smaller than active mines and thus the amount of waste rock generated is also smaller (see Table 3-4). However, for the inactive surface or open-pit mines, the waste piles have generally not been

TABLE 3-8
REFERENCE UNDERGROUND URANIUM MINE PARAMETERS

<u>Parameter</u>	<u>Reference Mine</u>
Expected Mine Life (years)	30
Ore Production (MT/day) (MT/year) ^a	570 1.6 x 10 ⁵
Average Ore Grade (% U ₃ O ₈)	0.15
Average Grade of Waste (% U ₃ O ₈)	0.03
Average Grade of Sub-Ore (% U ₃ O ₈)	-
Production of Waste (MT/year) ^a	2.2 x 10 ⁴
Production of Sub-Ore (MT/year) ^a	-
Waste Pile After Shutdown	
Area (m ²)	6.9 x 10 ⁴
Weight (MT)	6.6 x 10 ⁵
Volume (m ³)	3.3 x 10 ⁵ ^b

^a Based on 286 days of operation per year.

^b Used a density of 2 g/cm³.

TABLE 3-9
CHARACTERISTICS OF INACTIVE URANIUM MINES
Source: EPA82

<u>Parameter</u>	<u>Reference Inactive Open-Pit Mine</u>	<u>Reference Inactive Underground Mine</u>	<u>Reference Active Open-Pit Mine</u>	<u>Reference Active Underground Mine</u>
Period of Mining (years)	17	15	17	30
Ore Produced (MT)	4.7×10^4	3.0×10^4	7.1×10^6	4.8×10^6
Waste Rock Produced (MT)	1.2×10^6	9.7×10^3	7.8×10^6 b	6.6×10^5
Density of Ore and Rock (g/cm^3)	2	2	2	2
Surface Area of Waste Rock Pile (m^2)	6.0×10^5 a	4.1×10^3		6.9×10^4

a Assumed a pile height of 1 m and a density of $2 \text{ g}/\text{cm}^3$.

b This is the subore from all 19 pits. The overburden has not been added in.

placed in the mine pits, as is often done with present-day mines.

Comparison of the postulated ore production figures for the reference inactive mine (Table 3-9) to the ore production distribution figures in Table 3-4 indicates the assumed averages are only characteristic of a few mines. The distribution of mine sizes is skewed with a few large mines causing the average value for mine production to be considerably larger than the median value. For example, more than 60% of the inactive underground mines are smaller than the reference inactive underground mine, and more than 30% are a factor of more than 300 smaller than the reference mine. The EPA82 reference inactive mines are selected as the best technique for characterizing the inactive mines.

3.1.2 Existing Contamination

The waste piles from the mines, as described for the reference facilities, constitute the majority of the existing contamination. The radioactivity will be composed of uranium-238 and its decay products (essentially in equilibrium). Concentrations will vary from background (i.e., 1 to 2 pCi/g of U-238) for some overburden to over 120 pCi/g for waste from some underground mines. Subore piles, especially from older mines can be expected to range up to 140 pCi/g or more. The reference surface mine overburden pile has an average concentration of 8 pCi/g and the concentration in the subore pile is 65 pCi/g. All these values are for U-238. Equal concentrations of U-234, Th-230, Ra-226, etc., will also be present.

The above concentrations all generally exceed the proposed EPA standards for inactive mill sites (EPA80, EPA81). There will also be a small

volume of waste from equipment and structures, but most of the equipment can be cleaned up sufficiently to use it in other mining areas. The total volume of waste is estimated from the average waste piles described. It should be noted however, that extrapolating the average numbers based on only a few mines results in some uncertainty.

3.1.3 D&D Alternatives And Wastes

There are no generally applicable standards for wastes from uranium mining. Although the types of materials and hazards are similar to uranium mill tailings, the standards being developed for uranium mill tailings are not directly applicable. There is some thought of including mine wastes under the EPA78 Solid Waste Disposal Act as amended by the Resources Conservation and Recovery Act of 1976 (EPA82). The basic exposure pathways for mine wastes are:

- The use of mine waste in building structures (primary concern would be the exposure of people to elevated concentrations of radon and its progeny).
- The dispersion of mine tailings with the resulting contamination of the surrounding land and water (basic concerns are radon exposure and possibly toxic trace metals in water and food pathways).
- Radon release from the waste piles and the resulting exposure of nearby individuals and regional and distant population groups to elevated ambient concentrations of radon and its progeny.

There would also be some external gamma exposure from contaminated land and structures where mine wastes are used.

Past practice and present regulations generally require minimal, if any, D&D at uranium mine sites. Because of the lack of Federal guidance

and the large volume of wastes, which thus entail a potentially large cost for D&D, D&D alternatives are not specified. Rather, the associated volumes are identified and the wastes characterized.

The wastes from the reference mines are identified in Section 3.1.1. These estimates will be applied to actual mines in Section 3.2. The wastes are fractured rock and overburden soils. The material has not been specifically ground or crushed. Therefore, it will range from large rocks to fine grained sands and clays.

The radioactive content will be primarily U-238 and its decay products. The chemical forms of uranium, thorium, and radium will be their natural forms. However, there is a potential for a change in the chemical form of uranium and radium, and thus their solubilities, as the material is exposed to the atmosphere and surface water.

Trace amounts of molybdenum, arsenic, selenium, and other toxic metals which were present in the original material may also be present (Ka81, EPA82, NRC80).

The materials at a mine site may include a minimal amount of structural material and possibly some mining equipment, and wastes from the mining operation. The structural materials and mining equipment may be decontaminated and reused, depending on transport distances and cost considerations.

The mine wastes are generally segregated into waste piles and subore piles. The uranium concentrations of these piles will depend on the ore body, the milling operation, and haulage distances to the mill. That is, low-grade ore can be hauled to a nearby mill but cannot be cost-effectively hauled to distant mills. Generally the subore pile contains material that

was just below the grade of economic recovery during the operation.

3.2 ACTIVE AND INACTIVE URANIUM MINES

3.2.1 Description Of Uranium Mines

The active and inactive mines have been previously described in the introduction to this chapter and in Section 3.1. The locations of active mines are listed in Appendix A. Because of the large number of mines and variables affecting operations, estimates of the remaining operating life are not made.

A summary of the locations of inactive mines is given in Table 3-2. Available information on precise locations is given by EPA82, and is not reproduced here.

3.2.2 Existing Contamination

The existing contamination at uranium mines is primarily composed of the mine waste and subore piles, and contaminated surfaces around these piles and near the ore storage area. Although the surfaces of the mine will exhibit exposure rates above natural background levels, this will be due to remaining ore and subore concentrations of uranium in their natural setting (i.e., the material has not been removed from the earth even though mining has made it more accessible). Although the actual mine may represent a technologically enhanced exposure area, it is outside the scope of this report.

Estimates of the existing contamination for active and inactive mines,

both open-pit and underground, are given in Table 3-10. These estimates are scaled from the reference mines in Section 3.1, and a range of values is given.

The best estimate for the active open-pit or surface mine is based on the practice of placing most of the overburden in mined out pits (i.e., the overburden from only one pit is left on the surface; see Section 3.1). The subore, material just below the economical grade for recovery, is assumed to be left on the surface with the expectation that it may be economical to process it later.

The active reference open-pit and underground mines developed in Section 3.1 are based on published studies from selected operating mines. Although the mines are somewhat larger than the average operating open-pit or surface mine (data from EPA82 and DOE81a), they are based on the best available sources and are believed to characterize the active mines. The scaling factors in Table 3-10 are based on the production of the average active open-pit or underground mine (determined from DOE81a) divided by the production from the reference mine. For example, the average underground mine produced 19,000 MT of ore in 1980; whereas, the annual production of the reference mine is 160,000 MT--giving a ratio of 0.12. The average ore production from mines in 1978 and 1979 (DOE81a) was also evaluated in determining the scaling ratios.

A scaling factor of 1 is used for the active underground mines to provide an upper level estimate. However, the results based on the factor of 0.12 are considered to be the best estimate.

Estimates of existing contamination for the inactive mines are scaled directly from the reference mines and the number of inactive mines. These

TABLE 3-10
EXISTING WASTE AT URANIUM MINES
(Excludes Contaminated Surface Areas)

<u>Mine Type/Number of Mines</u>	<u>Reference Mine Parameters^a (10⁶ m³)</u>	<u>Scaling^b Factor</u>	<u>Waste (10⁶ m³)</u>
<u>ACTIVE MINES</u>			
<u>52 Surface Mines</u>	Sub-Ore--3.9	0.43 c	87
	Overburden		
	1 Pit--12 e	0.43 c	270
	19 Pits--230 e	0.43 c	5,100
SUBTOTAL for projected placement of overburden in pits ^{e,f}			360
SUBTOTAL if overburden not placed in pits ^e			5,200
<u>303 Underground Mines</u>	Waste--0.33	1 ^d	100
(Best Estimate)	Waste--0.33	0.12 d	12
SUBTOTAL, best estimate			12
<u>INACTIVE MINES</u>			
<u>1246 Surface Mines</u>	Total Waste--0.60	1	750
<u>2031-Underground Mines</u>	Waste--0.0048	1	10

a Taken from Tables 3-5, 3-6, and 3-8. Values have been converted from MT to cubic meters by using a density of 2 MT/m³. This density may be a bit high for some overburden.

b Multiplier is used to scale the reference mines to the average mine.

c Based on 1980 ore production divided by number of mines (DOE81a). See text for more detail.

d The scaling factor of 0.12 is based on 1980 ore production divided by the number of mines (DOE81a). See text for more explanation.

e The present trend for open-pit mining is to place the overburden from new pits into mined-out pits. At the end of the operations the subore, and overburden from a single pit are left on the surface.

f Subtotals are rounded off.

values are given in Table 3-10. Hans et al. (Ha81) report that the total waste produced from uranium mining between 1950 and 1978 was 1.7×10^9 MT. This estimate includes production from both active and inactive mines and is thus a conservative upper-limit estimate for the amount of waste from inactive mines as of 1978. The total estimated waste from inactive mines, from Table 3-10, is 1.5×10^9 MT, somewhat less than the value given by Ha81.

In addition to the wastes in Table 3-10 there is contaminated land from the ore stockpile area and from dispersion of waste by wind, water, and mechanical action around the waste piles. Douglas and Hans (Do75) report results for inactive mill tails piles that indicate the contaminated area may be two or more times the pile area. Because of the lower concentration in mine wastes, a contaminated area equal to the pile area is assumed.

Estimates from Ja80 indicate the ore pile may cover about 2000 m^2 for the reference underground mine site, based on an average depth of 0.5 m. The ore is probably stacked higher than 0.5 m, but ore will also be spread around the area. For the average mine site, the value for the reference mine is reduced by a factor of 0.12 to 240 m^2 .

The yearly ore production for the reference surface or open-pit mine is about 2.6 times that for the underground mine. By scaling linearly, this indicates an area of about 5000 m^2 . Thomas et al. (Th82) report a value of $2.2 \times 10^4 \text{ m}^2$ for a mine in mid-life with nine operating pits. The value from Th82 indicates that the same ore pile is not used by all pits. Using the previous scaling factor of 0.43 and the ore stockpile area from Th82 gives an average area of $9.5 \times 10^3 \text{ m}^2$.

The values for the inactive sites are estimated to be about

one-hundredth of the values for the active reference sites based on the relative ore production rates. These values are 20 and 220 m², respectively, for the underground and surface mines.

The contaminated areas around the waste rock (subore for surface mines) sites are assumed to be equal to the area of the sites. These values are 7x10⁴ and 4x10³ m² for active and inactive underground mines, respectively, and 4x10⁶ and 1.2x10⁶ m² for active and inactive surface mines, respectively.

The above values are used in Table 3-11 to calculate the contaminated surface areas. The actual area of waste rock piles is not included in these estimates. The estimates in Table 3-11 indicate that the contaminated areas around the waste piles (subore) of open-pit mines are the controlling values for the estimates of contaminated areas. It is assuming that these areas could be cleaned by removing an average of 10 cm of the surface material. That is, the values can be converted to cubic meters by multiplying by one-tenth. Concentrations are projected to range from 5 to 50 pCi/g of U-238 and its decay products.

As noted in Section 3.1, inactive mines are not uniformly distributed in size. A large fraction of the waste is associated with a relatively small number of sites.

3.2.3 D&D Alternatives and Wastes

The D&D alternatives are discussed in Section 3.1.3; they will not be repeated. The volume of wastes is given in Table 3-10. Estimates of the contaminated surface areas are given in Table 3-11. It is not clear whether all the wastes should be classified as D&D wastes since there are

TABLE 3-11
CONTAMINATED SURFACE AREAS AROUND URANIUM MINES*

<u>Type of Mine</u>	<u>Number of Mines</u>	<u>Contaminated Area Per Mine</u>		<u>Area For All Mines</u>	
		<u>Ore Stockpile (m²)</u>	<u>Area Around Mine Waste Pile (m²)</u>	<u>Ore Stockpile (10⁶m²)</u>	<u>Area Around Mine Waste Pile (10⁶ m²)</u>
Active Mines					
Open-Pit	52	9,500	2x10 ⁶	0.49	100
Underground	303	240	7x10 ⁴	0.073	21
Inactive Mines					
Open-Pit	1246	220	6x10 ⁵	0.27	750
Underground	2031	20	4x10 ³	0.041	8
TOTAL Area				880	

* Based on ore stockpile area and area around surface and mine waste piles (excludes pile areas and specific overburden waste from surface mines).

no specific standards.

As noted in Section 3.1.3 the materials are primarily soils and rock with elevated concentrations of U-238 and its decay products. Concentrates of U-238 are expected to range from 5 to over 100 pCi/g (reference mines Tables 3-5, 3-8, and 3-9). Nominal concentrations of U-238 are expected to be around 50 pCi/g.

Residual materials are briefly discussed in Section 3.1.4. Subore could be processed for uranium and mining equipment will probably be reused.

Estimates of the existing contamination for active and inactive surface and underground mines are given in Table 3-10. These estimates are based on the reference mines from Section 3-1. A range of values is given for the active mines.

The best estimate for the active surface mine is based on the practice of placing most of the overburden in mined out pits (see Section 3.1). The reference mine contains 19 pits. The overburden from the first two pits is placed on the surface and the overburden from subsequent pits is placed in mined-out pits. At the completion of operations this leaves 17 pits filled with overburden, two empty pits, and two piles of overburden on the surface (the subore is also on the surface). Before the site is abandoned it is assumed some reclamation is done. It is assumed one pile of overburden is left (e.g., half the time they are both left and half the time they are both moved).

The subore is material just below the economical grade for recovery. It is assumed this is left on the surface with the expectation that it will be economical to process it later.

As noted in Section 3.1 the reference surface mine (based on Ni79 and Th82) is somewhat larger than the average surface mine. A scaling factor of 0.43 has been used in Table 3-10. This factor is based on comparing the reference mine ore production to the total surface mine production in 1980 divided by the number of mines. This is equivalent to scaling the surface mine production and number of mines to the reference mine. Use of a scaling factor for the large versus average mine in EPA82 yields a similar factor. As an additional comparison, based on the average ore production for 1978, 1979, and 1980 (DOE81a), a factor of 0.4 is obtained.

4. URANIUM MILLING

Uranium mills process ore to recover uranium. The basic mill procedures are crushing the ore, leaching the uranium from the ore, and recovering semi-refined uranium--yellowcake--from the leachate. Since almost all U.S. ores contain less than 0.5% uranium, most of the ore is waste and is discharged to a mill waste or tailings pond. This chapter is oriented towards conventional mills; however, heap-leach, by-product recovery, and solution mining operations are also included. Inactive mills (DOE80) were covered in the federal facilities report, Be82.

In 1978, the capacity of individual conventional mills ranged from 360 to 6300 MT of ore per day, with an average capacity of 1800 MT per day--the basis of the NRC model mill in NRC80. Nineteen mills were operating in early 1978; this figure increased to 22 in early 1980. The average mill size remained the same since most new mills have a capacity of about 1800 MT per day. The other types of plants for uranium recovery tend to be smaller.

The conventional mill operation is commonly used where there are large volumes of ore to be processed. Solution mining operations are more common for extracting uranium from pockets of uranium ore that do not justify the expense of conventional mining and milling operations. Heap leaching is a method of salvaging uranium from low-grade ores, or possibly from ores mined at remote locations where it is not economical to transport the ore to a mill. By-product recovery facilities have been used in conjunction with other mineral milling industries (e.g., copper, phosphate, and gold) when the subject ore also contains economically recoverable quantities of

TABLE 4-1
CONVENTIONAL URANIUM PROCESSING PLANTS

<u>Location</u>	<u>Company</u>	<u>Common Name</u>	<u>Maximum Capacity (MT per day)</u>	<u>Year Milling Started</u>
<u>COLORADO</u>				
Canon City	Cotter		1100	1958
Uravan	Union Carbide ^{b,h}	Uravan	1200	1915
<u>NEW MEXICO</u>				
Seboyeta	Sohio/Reserve Oil & Minerals ^b	L-Bar	1500	1976
Church Rock	United Nuclear ^{b,h}	Church Rock	2700	1977
Grants	Anaconda ^b	Bluewater	6200	1953
Grants	Kerr-McGee	--	6400	1958
Grants	Homestake Mining Co.	--	3100	1958
Markquez	Bokem (not operated) ^h	--	1800	--
<u>SOUTH DAKOTA</u>				
Edgemont	TVA ^a	--	500	1956
<u>TEXAS</u>				
Falls City	Continental Oil/ Pioneer Nuclear ^b	Conquista	3100	1972
Panna Maria	Chevron Resources	--	2300	1979
Ray Point	Exxon ^b	Susquehanna	800	1970
<u>UTAH</u>				
Blanding	Energy Fuels Nuclear ^f	White Mesa	1800	1980
La Sal	Rio Algom	Lisbon	680	1972
Moab	Atlas	--	1300	1956
Shootaring Cy	Plateau Resources ^{e,h}	--	600	1982
<u>WASHINGTON</u>				
Ford	Dawn Mining ^{f,h}	Ford Mill	410	1957
Wellpinit	Western Nuclear ^{b,h}	Sherwood	1800	1978
<u>WYOMING</u>				
Powder River	Rocky Mt. Energy	Bear Creek	1800	1977
Powder River	Exxon ^{g,h}	Highland	2900	1972
Gas Hills	Federal-American ^{b,h}	--	860	1959
Gas Hills	Pathfinder ^c	Lucky Mc	2300	1958
Shirley Basin	Pathfinder ^c	Shirley Basin	1600	1971
Shirley Basin	Petrotomics	--	1400	1962
Gas Hills	Union Carbide	Gas Hills	1300	1960
Jeffrey	Western Nuclear ^{b,h}	Split Rock	1500	1957
Converse County	TVA ^{d,h}	Morton Ranch	--	--
Rawlins	Union Oil/Mineral Exploration ^h	Red Desert	3000	1981

a Mill inactive, tailings to be moved. TVA plans to rebuild at a new location.

b Mill inactive, on standby.

c Formerly Lucky Mc Mining and, before that, Utah International.

d Planned by United Nuclear, sold to TVA, not built, scheduled for 1986.

e Shutdown, only operated several months, plan to restart in 1984.

f Plan to shutdown.

g Plan to shutdown permanently in December 1983 and clean site.

h The operating status of mills was updated for the final report based on personal communications with Mr. John Lindehan, NRC, Denver, CO, January 17, 1983, and Mr. Harry Pettengill, NRC, Washington, DC, January 18, 1983.

TABLE 4-2

OTHER URANIUM PROCESSING PLANTS
Source: DOE81a

<u>Company Name</u>	<u>Plant Location</u>	<u>Production (MT U₃O₈/Year)</u>
Solution Mining Operations		
Everest Mineral Corp.	Hobson, TX	
IEC Corp.	Three Rivers, TX	
Mobil Oil Corp.	Bruni (O'Hern), TX	
Mobil Oil Corp.	Bruni (El Mesquite), TX	
U.S. Steel Corp.	George West, TX	
U.S. Steel-Niagara Mohawk	George West, TX	
Uranium Resources, Inc.	Bruni (Longoria), TX	
Uranium Resources-Conoco-Framco	Bruni (Benevides), TX	
Wyoming Mineral Corp.	Bruni, TX	
Wyoming Mineral Corp.	Three Rivers, TX	
Wyoming Mineral Corp.	Irigaray, WY	
TOTAL		1,500-1,900
By-Product Production		
Phosphoric Acid		
CF Industries/IMC	Bartow, FL	
CF Industries/IMC	Plant City, FL	
Earth Sciences, Inc.	Calgary, Alberta*	
Freeport Uranium Recovery Corp.	Uncle Sam, LA	
Gardiner, Inc.	Tampa, FL	
IMC Corp.	Mulberry, FL	
Wyoming Mineral Corp.	Pierce, FL	
Copper		
ANAMAX Mining Company	Sahuarita, AZ	
Wyoming Mineral & Kennecott Corp.	Bingham Canyon, UT	
Beryllium		
Brush-Wellman	Delta, UT	
TOTAL		870-1,250
Heap-Leach Mines		
Solution Engineering, Inc.	Falls City, TX	
Union Carbide Corp.	Maybell, CO	
TOTAL		100-250

* Listed by DOE81a.

the lifetime of the parent process.

Conventional uranium mills produce large quantities of tailings which must be disposed of. The common procedure has been to pile the tailings in the immediate vicinity of the mill and leave them there. Current federal regulations restrict this activity, however, and require that the tailings be disposed of in a safer manner. A uranium tailings pile must be covered to minimize dispersion of the tailings, to reduce the radon flux from the tailings, and to reduce the possibility of plant, animal, or human intrusion into the tailings. It is also necessary to assure that the tailings will not contaminate underground or surface water.

The most important and costly issue for D&D of mills is the proper disposal of the tailings. As a result of past disposal techniques and minimal stabilization prior to abandoning sites, the nation is faced with costly remedial action at some 25 inactive mill tailings sites (Be82, NRC80, DOE80, EPA80a). EPA has issued draft disposal standards for inactive sites (EPA80a, EPA81) and is presently preparing the final standards as well as standards for active sites.

The NRC (NRC80) has evaluated decommissioning alternatives for uranium mills. Quoting from NRC80:

"The alternatives to be considered are: (1) the retention and use of some or all of the buildings and equipment after decontamination, and (2) the complete removal of all buildings, foundations, and equipment, with the restoration of the site to its original state. The abandonment of the mill and site without decontamination and with or without fencing and guards is not considered a viable alternative."

The NRC now requires submission of a decommissioning plan prior to issuing a mill license.

4.1 REFERENCE URANIUM MILLS

Because of the large number of mills reference facilities are developed to aid in the assessment of D&D wastes for individual mills. The reference facilities are generally based on published reports. Waste estimates for actual facilities are obtained by using estimates for the reference facility and pertinent process scale factors.

Two basic processes are used to remove uranium from ore: the acid leach process, which uses sulfuric acid, and the carbonate or alkaline leach process, which uses a carbonate solution. About 80% of the current milling capacity uses the acid leach process.

Since the acid leach process is predominant, and there are minimal differences in the processes from the viewpoint of D&D, the reference mill will be based on the acid leach process.

4.1.1 Description Of Reference Facilities

4.1.1.1 Conventional Acid Leach Mill Process

This section is based on the model mill from NRC80. The emphasis is placed on characteristics related to D&D rather than environmental releases.

Uranium is recovered from ore and concentrated in an intermediate semi-refined product, often called yellowcake. The intermediate product is transported to uranium hexafluoride conversion plants for further refinement and eventual enrichment. The milling process involves (1) ore handling and preparation, (2) hydrometallurgical extraction or leaching of the uranium from the ore and concentration of the product, and (3) product

recovery by chemical precipitation and drying (drying can be excluded) and packaging the product.

Ore Handling and Preparation - Ore is generally brought to the mill by truck and deposited on the ore storage pad. The volume of ore accumulated on the pad varies from several days' to several months' supply (areas where weather only permits mining during certain seasons) (NRC80).

Ore is moved from the storage area to bins which supply feed to ore crushers. Jaw crushers are used in one or more stages to reduce the ore to a size range of about 1.9 to 3.8 cm. Dust control during the crushing operation is usually provided by placing exhaust hoods at strategic locations. Excessive moisture in the ore can adversely effect ore handling characteristics. Natural drying or kiln drying may be required to reduce the moisture content to 5% or less during winter months or to 10% or less the rest of the year. Mills usually have fine ore storage capacities equivalent to double the rated daily mill capacity.

Some uranium ores are roasted to increase the solubility of valuable constituents and to improve the physical characteristics of the ore. For example, ores are roasted to enhance vanadium extraction, to improve the ore settling and filtration characteristics by alteration of clay minerals in the ore, and to remove organic carbon which can cause problems in the leaching circuits.

Ore characteristics and the leaching process used dictate the degree to which ore must be ground. For the acid leaching of sandstone ores, the ore is ground to liberate the natural grain size. Rod and ball mills are usually employed to affect a size reduction of the ore to approximately 28 mesh (600 microns) for the acid leach process. Alkaline leaching is more

selective and much finer grinding is required to expose the uranium values. The ores are wet ground (water added), resulting in a pulp density of 50 to 65% solids with the aid of classifiers, thickeners, cyclones, or screens which size the ore and return coarser particles for further grinding. From the crushing circuit, the ore is conveyed to the grinding circuit by belt-type feeders at the desired feed rate.

Semi-autogenous wet milling can be used in place of both the crushing and fine grinding. This process uses a rotating steel cylinder. The tumbling action of the lifters, large pieces of ore, and a small charge of 8- to 10-cm steel balls breaks down the ore. Wet milling minimizes the amount of dry ore handling, and the resulting airborne material (NRC80).

Extraction of Uranium - The uranium is recovered from the ground ore by leaching techniques. The slurry from the grinding operation (50 to 65% solids) is discharged into the leaching circuit, which consists of several tanks in series. The ore leaching proceeds at atmospheric pressure and a little above room temperature for about seven hours. The uranium content of the ore is dissolved, along with other materials present in the ore (e.g., iron, aluminum and other impurities).

After ore leaching is completed, the pregnant leach liquor containing the dissolved uranium is removed from the tailings solids in a counter-current decantation (CCD) circuit. After thorough washing, the sands and slimes are pumped as a slurry to the tailings pond. The dry weight of the tailings basically accounts for the total weight of the processed ore, with the exception of the very small weight of the uranium values that were extracted (NRC80).

After solid-liquid separation of the CCD circuit, the leach solution

is sent to the solvent extraction process. Several extraction tanks in series (e.g., four stages) are used to recover uranium from the leach liquor (aqueous phase) by countercurrent contact with an organic solvent (organic phase). Uranium forms a complex with the organic solvent, and in an excess of the solvent this complex is so soluble that the uranium is quantitatively extracted from the aqueous phase. The immiscibility of the solvent in water aids separation and the lighter uranium-loaded organic layer rises to the surface and is separated by decantation. The uranium is then stripped from the organic phase and the stripped organic phase is recycled to the solvent extraction circuit for reuse (NRC80).

Ion exchange techniques may be used as alternatives to organic extraction. The clarified uranium solution may be passed through ion exchange columns or the non-classified slime fraction may be directly contacted with ion exchange resin contained in baskets. This latter process is the resin-in-pulp or RIP process. The Eluex process is a combination of ion-exchange and solvent extraction (NRC80).

The uranium that has been transferred from the organic phase to the aqueous strip solution is precipitated from solution by addition of gaseous ammonia, sodium hydroxide, hydrogen peroxide, or magnesium in several stages, with the pH properly controlled. In most mills, gaseous ammonia is used as a precipitating agent. The uranium is precipitated as a diuranate (usually ammonium diuranate) commonly called yellowcake.

Drying and Packaging - The precipitated uranium is dewatered in thickeners and then filtered and washed in drum, plate, or frame filters. The resulting filter cake still contains considerable moisture and is generally dried in a continuous steam-heated dryer or in a multiple hearth

dryer operation at 370° to 430°C (700° to 800°F). The dried product contains an amount of uranium equivalent to 80 to 96 percent U_3O_8 . The dried yellowcake is packed in 200 l (55 gal) drums for shipment to a uranium hexafluoride conversion plant.

Airborne effluents from the yellowcake drying and packaging operations are the major effluents from the milling process (exclusive of radon from the tailings pile). Modern mills use wet scrubbers for cleaning the dryer effluent and scrubbers or bag filters for the packaging effluent.

An alternative to the drying and packaging operation is shipping the yellowcake as a wet cake or slurry. The Kerr-McGee conversion plant can process wet yellowcake; however, the Allied plant cannot (see Chapter 5).

The precipitated uranium concentrate is ammonium diuranate, $(NH_4)_2U_2O_7$ (or sodium or manganese diuranate), which is a bright yellow, cake-like material. Ammonium diuranate is stoichiometrically 76% uranium, but is often stated to be about 90% U_3O_8 (U_3O_8 is 85% uranium). The proper statement is that the uranium content of yellow cake is equivalent to the uranium content of 90% pure U_3O_8 .

The actual chemical composition of the yellowcake and thus contamination in the mill depends on the dryer temperature. The uranium in ammonium diuranate is hexavalent. If it is dried at temperatures of about 200°C, the uranium remains hexavalent, but some of the material is converted to uranium trioxide or its associated hydrates. Most of the ammonia is driven off at temperatures above 320° to 370°C, with fairly complete conversion to the trioxide at about 450°C. At about 400°C the uranium trioxide begins to decompose. Conversion to U_3O_8 (combination of hexavalent and tetravalent) starts to decompose and converts to UO_2 . These

conversions can generally be related to changes in the color of the product from pale yellow, to dark yellow, to orange or red, to green, and eventually to black. Sodium and manganese diuranate do not undergo these changes (Me71).

The solubility of uranium in body fluids is dependent on the chemical form, especially the valence state. The solubility decreases with the transformation from ammonium diuranate to U_3O_8 or UO_2 (Mo72, Mo66, Ka79).

Recent studies (Fo80 and Mo79) indicate that less than 1% of the uranium decay products, Th-230, Ra-226, and Pb-210, are carried over to the yellowcake.

Waste Disposal - Essentially all of the mass and most of the radioactivity from the ore are discharged to the tailings pile. The mass of the product uranium, roughly 0.1% of the ore, only amounts to 1 kg per MT. This amount of mass is more than replaced by process chemicals. About 10% of the uranium and essentially all of the Th-230 and Ra-226 in the ore are discharged to the tailings. Very little of the Ra-226 is solubilized in the mill process. Therefore, the Ra-226 is generally partitioned in its natural distribution between the sands and slimes fractions of the tailings. The majority of the Ra-226 is associated with the slimes, which represent less than half of the tailings. A large fraction of the thorium is solubilized in the milling process. It then precipitates when the pH is increased. Therefore, the distribution of Th-230 in the tailings may be different than that for Ra-226. The NRC80 model mill postulates an average ore grade of 0.1% which results in 283 pCi/g of Th-230 and Ra-226 in the tailings.

For early mills there was minimal concern for D&D and the health risks

associated with tailings. The criteria for the location of tailings piles was economics and ease of operations.

It was not until 1976 that the NRC made a concerted effort to control uranium mill tailings. Performance objectives were issued in 1977 and are given in revised form in Regulatory Guide 3.11 (NRC77). These objectives provide location criteria, specify eliminating blowing tailings, and require reducing the post-reclamation gamma exposure to off-site areas to essentially background levels. Furthermore, this guidance discourages the use of upstream dam construction techniques (the dam is raised in stages on the tailings material) and specifies minimizing seepage by use of clay or artificial liners.

The Nuclear Regulatory Commission amended its regulations in 1980 to specify licensing requirements for tailings disposal (NRC80a). The NRC specified that the conditions of tailings disposal areas should be virtually the same as conditions in the surrounding area and should remain so without active care and maintenance. The regulatory changes include an amendment to 10 CFR 40 requiring licensees to provide written specifications concerning mill operation and disposal of the tailings indicating how the requirements and objectives of 10 CFR 40 will be achieved. Some of the criteria in the amendments are: alternatives for site selection should be based on being able to maintain isolation for thousands of years without active maintenance, primary emphasis shall be given to long-term isolation versus consideration only of short-term convenience, the prime option for disposal is placement below grade, and sufficient earth cover (but not less than 3 m) shall be placed over the tailings to reduce the calculated radon flux from the tailings or waste to less than 2 pCi/m²-sec (NRC80a).

The reference conventional mill, based on the NRC80 model mill, has a capacity of 1800 MT of ore per day. An ore grade of 0.1% U_3O_8 is postulated, which is somewhat lower than the present average ore grade. This reference mill is similar to the base case used by EPA76.

The parameters for the mill are:

- Mill capacity: 1800 MT ore/day operating 310 days per year--about 600,000 MT/year. Production of 580 MT of yellowcake per year.

U_3O_8 Product: Ore grade 0.1%, uranium processing efficiency of 93%.

- Ore Storage: Ore pad 8 ha.

- Mill Site:

Total property 300 ha (750 acres).
Mill, excluding tailings 50 ha (125 acres).
Tailings impoundment 100 ha (250 acres).

- Tailings impoundment (area of 100 ha):

Actual tailings area: 80 ha.
Density: $1.6g/cm^3$.

- The mill is operated for 15 years.

Information is given by NRC80 for a reference site, population, and meteorology and dose pathways, but this information is not pertinent to D&D.

Table 4-3 gives a brief summary of equipment categories for a conventional mill. Some of the equipment, that associated with the solvent extraction circuit, is similar to the equipment in a uranium hexafluoride conversion plan. However, given the larger mass production of the reference mill (600,000 MT/year compared to 10,000 MT per/year for a hexafluoride conversion plant), the equipment in the mill must be considerably larger than that in the conversion plant.

TABLE 4-3
EQUIPMENT AND FACILITIES FOR THE REFERENCE MILL

Ore Storage Pad
Ore Dryer
Ore Storage Bins
Ore Crushers & Grinders (more than one)
Fine Ore Storage Bins (more than one)
Leaching Tanks (7 or more tanks)
Decantation Circuit (separates tailings from leach solution)
Solvent Extraction Circuit (Four Stages)
Separation of Uranium and Precipitation of Ammonium Diuranate
Yellowcake Drying and Packaging
Ore or Yellowcake Roaster
Air Cleaning Equipment
 Bag Filters
 Scrubbers

4.1.1.2 Reference Heap-Leach Facility

The NRC80 model conventional mine includes a heap-leach operation. The mill is not designed to process ores of less than 0.04% U_3O_8 and it is generally not cost effective to haul the low-grade ores to the mill. A heap-leach operation is based on placing ore in an impoundment where a leach solution can be recirculated through the ore. The bottom of the impoundment is lined with polyethylene sheeting. Perforated plastic pipe is placed at the bottom to collect the leach solution. The solution is recirculated to the surface and allowed to percolate through the pile. When the solution reaches a concentration of 0.1 to 1 g/l (U_3O_8 equivalent) it is either taken to a mill or processed on site to recover the uranium. If mine water is used, the uranium in the mine water is also recovered.

The residual ore (leached) for the reference site contains about 0.01% U_3O_8 and up to about 100 pCi/g of Th-230 and Ra-226. The pile covers an area of about 14 ha, to a depth of about 6 m (i.e., about $8.4 \times 10^5 \text{ m}^3$).

A heap-leach operation will generally be associated with a mill, or possibly a mine and its operating life is dependent on the operating life of the associated facility. An operating life of 15 years is estimated (based on the conventional reference mill). The defined parameters and operating lifetime relate to production of 40 MT of U_3O_8 per year. Any process equipment (may be skid mounted) will probably be moved to another facility.

4.1.1.3 Reference In-Situ Mining Facility

In-situ, or solution, mining is employed to recover uranium from

low-grade ores that are not economically recoverable by conventional mining methods. The process consists of introducing suitable leaching solutions into the underground ore body to solubilize the uranium minerals, pumping the solutions to the surface, and recovering the uranium. Advantages of this method include the elimination of hazards associated with normal underground mining and elimination of the need for handling large quantities of material and disposing of solid waste products. The requirements for solution mining are (An68): the uranium ore must lie in a generally horizontal bed above a relatively impermeable stratum; the ore must be located below the static water table; the direction and speed of regional water flow must be known, and the uranium minerals in the ore must be amenable to the proposed leaching process.

Solution mining is carried out by drilling inflow wells into the ore body upstream of a production well. Salt solutions of ions, such as sulfate, bicarbonate, carbonate, and ammonium, known to form stable aqueous complexes with hexavalent uranium, are pumped to the inflow well, and, simultaneously, there is a withdrawal of a slightly greater volume of solution from the production well. A solution of oxidant (NaClO_3) may be added to increase leaching efficiency. The inflow of solution is continued until the leach zone is depleted.

The ore body is a basic part of the process circuit. The leaching solution, well design and spacing, and flow rates are dependent on the mineralogy and the hydraulic properties of the ore body. Some control of groundwater flow is gained by diverting part of the barren solution, thereby injecting less than is withdrawn. The groundwater influx limits the excursion of lixiviant out of the localized well field area.

Uranium is recovered from the lixiviant by ion exchange and uranium precipitation processes similar to conventional mills. The uranium is produced as yellowcake. Contaminants such as sulfate and vanadium are also sorbed on the ion exchange resin and stripped into the elution and precipitation circuit along with uranium. In the absence of any control, the concentration of such contaminants builds up and affects the product purity and/or elution process efficiency. For contaminant control, a bleed-off stream of some of the contaminated recycle elutant is bled off and replaced with an equal amount of fresh elutant. The nature, level, and even the need of contaminant control depend on the composition of the ore body and the chemistry of the specific solution mining process.

Calcium may precipitate as calcite (CaCO_3) in basic leach solutions or as gypsum (CaSO_4) in sulfuric acid leach solutions. Either precipitate can plug injection and production wells or interfere with the ion exchange process. Calcium removal units may be placed in the lixiviant sorption circuit to mitigate calcium-related problems.

Liquid and solid wastes and atmospheric effluents result from solution mining activities. Liquid wastes result from well field overpumping (i.e., production flow in excess of injection flow), elution and precipitation circuit bleeds, and subsequent aquifer restoration. Since the dissolved solids content of the wastewater precludes uncontrolled releases, waste management is necessary. Generally, evaporation ponds are utilized; however, deep well disposal has been used in Texas. The recycle of waste water requires removing contaminants, but reduces the amount of water used and discharged as waste.

Solid wastes generated include: calcium carbonate from the control

unit in the lixiviant sorption circuit, BaSO_4 if sulfate control is needed for the contaminant control unit in the elution and precipitation circuit, wastes from drilling wells, and sediments in ponds. During the life of a solution mining operation, solids may be impounded in specific storage ponds. They may be maintained and monitored under a liquid seal to minimize particulate emissions and radon gas evolution.

Less than 5% of the radium in the ore body is brought to the surface, with acid lixiviants. Alkaline lixiviants may dissolve several times as much radium. The amount of solid wastes and the associated Ra-226 from in-situ mining is much less than that associated with conventional mining (NRC80, EPA82, NRC78).

Water quality effects include excursions of lixiviants during injection and natural migration of residual lixiviants and other mine-affected groundwater after mining has ceased. After termination of solution mining operations, procedures are implemented to restore the water quality of the affected aquifer. Restoration will remove or immobilize chemical species injected or mobilized as a result of chemical actions in the ore body during mining. The restoration process is intended to reduce the mobilized species content and composition of the groundwater to levels set by appropriate regulatory agencies.

Groundwater restoration technology is still in the development stage. Current practice requires the pumping of large quantities of water from the aquifer (groundwater sweeping). By this technique, the contaminated water removed from the aquifer is replaced by groundwater entering the localized ore zone from the surrounding area or is replaced by purifying the contaminated water and reinjecting it into the aquifer. With proper

operation, the water entering the ore zone of the aquifer will gradually sweep the residual impurities from the solution mining operations toward the production wells, where they will be withdrawn to the surface. The efficiency of the sweeping action is limited and therefore requires large volumes of water.

Parameters for the reference in-situ or solution mine are:

- Ore body: 53 ha by 8 m thick ($4.2 \times 10^6 \text{ m}^3$).
- Average ore grade: 0.06% U_3O_8
- Ore density: 2 MT/ m^3
- Annual production: 227 MT of U_3O_8
- Lixiviant: Alkaline
- Calcite (CaCO_3) removal: 2 MT per MT U_3O_8
- Radium In Calcite: 2 Ci Ra-226/year (2.5% solubilized)
- U-238 In Calcite: 1.9 Ci/year

This reference in-situ mine is based on the hypothetical mine from EPA82. The annual production of U_3O_8 (227 MT) is equivalent to recovering 80% of the uranium from 470,000 MT of ore. Over the 10 year lifetime, this is equivalent to recovering the uranium from $2.36 \times 10^6 \text{ m}^3$ of the formation.

There is very little information on surface wastes from in-situ mining. However, calcite is one of the main contributors to the wastes. Assuming the wastes may be twice the calcite wastes results in a volume of 335 m^3 of wastes (density of 2.71 g/cm^3 for calcite) per year or $3,350 \text{ m}^3$ after 10 years. This is about one-thousand of the amount of tailings that would have been produced by a conventional mill. There would also have been mine wastes from mining the ore by conventional techniques.

Other sources of waste are sediments in evaporation ponds (e.g., about 1.4 ha of ponds, which should contain minimal radioactivity (EPA82), and the waste material from drilling monitoring and production wells. It is estimated about 500 wells are needed to recover the uranium. Assuming the wells (20 cm diameter) are drilled to a depth of 153 m, through an 8-m thick ore body will result in about 2,500 m³ of waste material, of which 5% will contain 0.06% U₃O₈. Assuming the drilling material is completely mixed, the concentration will be about 10 pCi/g.

4.1.1.4 Reference By-product Recovery Facility

In the U.S. uranium is recovered as a by-product from copper leach liquors or tailings, wet-process phosphoric acid plants, and a beryllium mill (NRC80,Fa79). The uranium is recovered as a by-product from ores mined for other purposes. The ores, tailings, and other basic waste products are present regardless of whether uranium is recovered and are not a result of the by-product recovery operation. Based on evaluations of conventional mills, the process equipment can be decontaminated after plant shutdown.

Since the tailings, the primary source of D&D wastes, are not directly related to the by-product recovery operation, a reference by-product recovery facility is not developed.

4.1.2 Existing Contamination At Uranium Mills

4.1.2.1 Existing Contamination at Reference Conventional Uranium Mill

Although there will be existing contamination in a mill the volume and

activity of the material will be insignificant compared to the tailings (8.4×10^6 MT or about 5.2×10^6 m³). Furthermore, since tailings piles are being designed for in place stabilization the waste from the mill can be disposed of in the tailings pile, and it is not necessary to package the material and ship it to a LLW burial site (NRC80).

The contamination in the various segments of the mill will reflect the chemical form and concentration of uranium in the different processes. In the ore sampling and crushing areas the contamination will be ore dust with a concentration ranging from 280 pCi/g (U-238 and each decay product) to about 670 pCi/g (concentration in fine ore dust is up to 2.4 times the average concentration) (NRC80). The uranium and progeny will be in an insoluble form.

In later stages of the process the uranium in solution is in the hexavalent or soluble state. The uranium is precipitated as a diuranate (hexavalent), and depending on the drying temperature, most of the product remains in the hexavalent state.

Using information from the uranium hexafluoride conversion facility (Chapter 5 and Appendix C) it is estimated that process equipment may contain roughly 10 g/m² of contaminating material (E181). The specific activity or concentration of this material will vary from 280 to 280,000 pCi/g depending where it is in the system (i.e., ore or uranium concentrate). The NRC assessment (NRC80) indicates most of the equipment can be decontaminated to allow unrestricted release or disposal. This is in general agreement with the evaluation of uranium hexafluoride conversion plants where it is concluded that most of the solvent extraction equipment can be decontaminated for unrestricted release (see Appendix C).

Parts of the structures will also be contaminated with leaked and spilled process solutions and airborne ore dust and uranium concentrate. The contamination from airborne dusts can be removed fairly easily, but porous materials (e.g., concrete, rubber, wood, and cinder block) contaminated with liquids will have to be disposed of unless the contamination is on the surface and the surface is removed.

4.1.2.2 Existing Contamination At Reference Heap-Leach Facility

The existing contamination is the heap-leach pile and any contaminated land around the pile. The estimates for the reference facility are a pile of $8.4 \times 10^5 \text{ m}^3$ with a concentration of about 100 pCi/g of both Th-230 and Ra-226. To some extent this material is already included in the estimates of mine wastes since much of this material is below the cutoff grade and would be classed as subore or mine waste.

4.1.2.3 Existing Contamination At Reference In-Situ Mine Sites

It is estimated that the total volume of solid wastes is about twice the volume of calcite wastes, or $3.4 \times 10^3 \text{ m}^3$. The concentration of Ra-226 in the wastes will be about 2,000 pCi/g if averaged throughout the total volume or about 4,000 pCi/g if averaged for just the volume of calcite wastes. The above volume includes some wastes from cleaning up small areas of the evaporation ponds and from contaminated material from the numerous drill holes required by the operation.

4.1.2.4 Existing Contamination At By-product Facilities

Since a reference facility was not developed estimates are not given.

4.1.3 D&D Alternatives and Wastes For Reference Uranium Mills

Essentially all of the existing contamination and D&D wastes at uranium mills relate to the tailings.

The basic D&D alternative for conventional mills is DECON, decontamination of the process equipment, mill and site property; disposal of the radioactive wastes in the tailings; and stabilization of the tailings pile. Minor alternatives are whether to decontaminate the buildings, or raze them and place contaminated material in the tailings pile. Because of the long half life of the radioactive materials SAFSTOR is not appropriate except for temporary shutdown for standby status.

NRC80 evaluates several alternatives for D&D. Basically two alternatives are specified. These are: "(1) the retention and use of some or all of the buildings and equipment after decontamination; and (2) the complete removal of all buildings, foundations, and equipment, with the restoration of the site to its original state. The abandonment of the mill and site without decontamination, and with or without fences and guards, is not considered a feasible alternative." Metal-surfaced equipment can usually be decontaminated and reused, or possibly transferred for restricted use without decontamination. Crushers, grinders, rod mills, valves, pumps, steel tanks, and similar items can usually be salvaged. For decontamination, simple procedures, such as sandblasting or scrubbing with detergents, should be successful. Porous materials, e.g., wood, fiberglass, plastic, concrete, concrete block, or rubber-surfaced equipment, generally cannot be decontaminated economically, and must be removed. Electric motors exposed to radioactive solutions usually cannot

be decontaminated (NRC80).

The NRC suggests that after removing salvagable equipment, non-salvageable equipment be buried in the tailings impoundment area. Contaminated building materials and pipe are also removed and placed in the tailings pile. For Option 2, removal of all buildings, uncontaminated foundations, etc. can be used as riprap on steep slopes (NRC80).

Areas outside the buildings where equipment is not located are to be treated identically in the two options. Heavily contaminated areas, such as ore pads and sludge or collection ponds, would be excavated, generally to a depth of less than a few meters, and the dirt removed to the tailings pile. The extensive on-site and off-site areas lightly contaminated by dust blown from the ore pad, mill and tailings are expected to be excavated to a relatively shallow depth (5 to 10 cm), with contaminated dirt being disposed of in the tailings impoundment.

The volume of tailings from the reference mill after 15 years of operation is 5.2×10^6 m³. Depending on mill operating policies (i.e., cleaning up spills when they happen) and prudent tailings pile management (i.e., controlling wind erosion), the D&D wastes from process facilities and the mill site will be less than one-tenth of the volume of the tailings pile. Surveys at inactive mill sites indicate that contamination around some of the sites covers about 10 times the area of the pile (Do75, EPA80a). However, for many of the piles the major fraction of the contamination, based on proposed standards (EPA81), is limited to an area of about twice the pile area (excludes actual pile).

Even if it is postulated that 1 m of surface material must be removed from the mill site (50 ha) and an average of 10 cm of material must be

removed from a 100 ha area around the tailings pile, the total volume is $6 \times 10^5 \text{ m}^3$ or about one-tenth of the tailings. Furthermore, the material removed would have a lower concentration of activity than the tailings and could possibly be used as a bottom layer in the pile cover.

NRC80 estimates that the surface meter of material would be removed from the 8 ha ore storage area and an average of 15 cm from 120 ha around the site for a total of $2.6 \times 10^5 \text{ m}^3$. This indicates that the above estimate is conservative, and provides additional evidence that the tailings account for essentially all of the wastes.

The tailings from the reference mill operation are assumed to contain 280 pCi/g of Th-230 and Ra-226 (each), the primary long-lived radionuclides in tailings. The inventories for the reference pile are 2,300 Ci of Th-230 and Ra-226 respectively. A conservative estimate for the maximum concentration in the waste material from cleaning up the mill site areas is 50 pCi/g, resulting in an additional 30 Ci of Th-230 and Ra-226.

If the tailings and other wastes are stabilized on the site, the transported D&D wastes are essentially zero. The total volume of wastes on the site is assumed to be $6 \times 10^6 \text{ m}^3$ ($5.2 \times 10^6 \text{ m}^3$ from tailings, rounded-up to account for wastes from D&D of the facility and site) and 2,300 Ci each of both Th-230 and Ra-226.

Alternatives for the location and final stabilization of piles are evaluated in NRC80. Final alternatives will be based on EPA standards for active mills, which are being developed (PL78). The NRC presently requires plans for D&D and stabilization of the tailings be initiated at the time of licensing (or license renewal for existing mills) (NRC80a). Agreement states are to develop compatible standards.

The D&D alternatives for heap-leach facilities are similar to those for mills. However, the concentration of residual radioactivity in the tailings will be a factor of two to three less than for mills because of the low ore grades (i.e., about 100 pCi/g). Much of the material would have been subore or mine waste if heap leaching had not been used. Based on the philosophy of proposed regulations for mills (EPA80, EPA81), the heap-leach piles should be treated similar to tailings piles and should be stabilized. The piles will probably not be consolidated with mill tailings piles because, if it were economical to move them, the material would have been taken to a mill in the first place.

The volumes of waste from in-situ mining operations are rather small, but the concentrations of activity are higher than for most tailings. Furthermore, most of the material contains concentrations of uranium similar to low grade ore. Therefore, the preferred D&D option is to clean up the site and move the waste to a conventional mill site, as is proposed by NRC80a. The material would be placed in the mill tailings pile with or without reprocessing to recover uranium. The primary objective of moving the material is to minimize the number of tailings repositories.

4.1.3.1 Volume and Activity of Materials

The volumes and activities of D&D wastes for the reference facilities are summarized in Table 4-4.

4.1.3.2 Chemical and Physical Form of D&D Wastes

The chemical and physical characteristics of the wastes have been discussed with regard to the specific reference facilities and will be

TABLE 4-4
D&D WASTES FROM REFERENCE MILL FACILITIES

Facility	Capacity Ore or U ₃ O ₈ (MT/year)	Ore Grade (% U ₃ O ₈)	Operating Lifetime (Years)	D&D Wastes	
				Volume (m ³)	Activity (Ci of Ra-226) ^a
Conventional Mill	600,000 (ore)	0.1	15	6x10 ⁶	2,300
Heap-Leach	110,000 (ore) 40 (U ₃ O ₈)	0.04 ^b	15	8.4x10 ⁵	190 ^b
In-Situ	230 (U ₃ O ₈) ^c	0.06	10	3.4x10 ³	20 ^d

a An equal amount of Th-230 and other uranium decay products are also present.

b Heap-leached ore is generally less than 0.04%. Therefore, these are upper level values.

c This is equivalent to recovering 80% of the uranium from 470,000 MT of the subject ore (0.06%) per year.

d There will also be about 19 Ci (58 MT of uranium) of U-238 present in the calcite.

considered in Section 4.2 for actual facilities.

4.1.3.3 Materials

The D&D waste is primarily composed of mill tailings and contaminated soil and building materials. A summary list of the process equipment is given in Section 4.1

4.1.4. Residual Materials

Essentially all of the mill process equipment and, depending on alternatives, the mill buildings are retained for future use.

4.2 ACTIVE URANIUM MILLS

4.2.1 Description of Mills

4.2.1.1 Conventional Mills

The active uranium mills are listed in Table 4-5, several mills that are shut down or on standby are also included. The age of the mills is given in the fourth column. About half of the mills have operated more than 15 years, the projected lifetime for the reference mill. The Uravan mill started out as a vanadium mill and has undergone numerous changes, including increasing the capacity.

Estimates of the D&D waste based on the reference mill are given in the column on the right. These values will underestimate the wastes when the mill has already operated considerably longer than the references lifetime of 15 years. The D&D estimates based on the reference mill have not

TABLE 4-5
CONVENTIONAL URANIUM MILLS

						Estimated D&D Wastes	
Location	Company	Capacity (MT per day)	Age	Ra-226 (pCi/g)	Amount of Tailings (x10 ⁶ MT)	Scaled	Based on
			of Mill in 1982 (Years)			From Mill ^a (x10 ⁶ m ³)	Reference Mill (x10 ⁶ m ³)
<u>COLORADO</u>							
Canon City	Cotter	1100	24	780	1.0	(1) ^c	3.7
Uravan	Union Carbided,n	1200	67	480	8.8	(6)	4.0
<u>NEW MEXICO</u>							
Seboyeta	Sohio/Reserve Oil & Minerals ^d	1500	6	500	1.4	4	5.0
Church Rock	United Nuclear ^{d,n}	2700	5	290	2.2	7	9.0
Grants	Anaconda ^d	6200	29	620	32	(30)	21
Grants	Kerr-Mcgee	6400	24	620	25	(20)	21
Grants	Homestake Partners ^h	3100	24	385	17 ^d	(20)	10.
Marquez	Bokem (not operated) ⁿ	--	--	--	--	--	--
<u>SOUTH DAKOTA</u>							
Edgemont	TVA ^g	500	189	560	2.3	(2) ^g	1.7
<u>TEXAS</u>							
Falls City	Continental Oil/Pio- neer Nuclear ^{b,n}	3100	10	1	5.6	7	10.
Panna Maria	Chevron Resources	2300	3	200	1.2	11	7.7
Ray Point	Exxon ^e	800	10	520	1.7	2	2.6
<u>UTAH</u>							
Blanding	Energy Fuels Nuclear ^m	1800	2	420	0 (New Mill)		6.0
La Sal	Rio Algom	680	10	560	1.6	2	2.3
Moab	Atlas	1300	26	540	7	(5)	4.3
Shootaring Cy	Plateau Resources ^{f,n}	600	- ^f	--	--	--	--
<u>WASHINGTON</u>							
Ford	Dawn Mining ^{m,n}	410	25	600	2.8	(2)	1.4
Wellpinit	Western Nuclear ^{d,n}	1800	4	200	1.3	7	6.0
<u>WYOMING</u>							
Gas Hills	Federal-American ^{d,n}	860	23	420	4.2	(3)	2.9
Gas Hills	Pathfinder	2300	24	420	5.8	(4)	7.7
Jeffrey City	Western Nuclear ^{d,n}	1500	25	430	11.0	(7)	5.0
Gas Hills	Union Carbide	1300	22	310	7.6	(5)	4.3

TABLE 4-5 (Continued)
CONVENTIONAL URANIUM MILLS

						Estimated D&D Wastes	
Location	Company	Capacity (MT per day)	Age of Mill in 1982 (Years)	Ra-226 (pCi/g)	Amount of Tailings (x10 ⁶ MT)	Scaled From Mill ^a (x10 ⁶ m ³)	Based on Reference Mill (x10 ⁶ m ³)
WYOMING (cont.)							
Powder River	Exxon ^{l,n}	2900	10	450	5.7	7	9.7
Powder River	Rocky Mt. Energy	1800	5	420	8.0 ^j	30 ^j	6.0
Shirley Basin	Pathfinder	1600	11	540	4.2	5	5.3
Shirley Basin	Petrotomics	1400	20	570 ⁱ	2.8	(2)	4.7
Converse County	TVAK, ⁿ	--	--	--	--	--	--
Rawlins	Union Oil/ Mineral Exploration ⁿ	3000	--	--	--	--	--
TOTAL					160	180 ^c	150

- a. The D&D wastes scaled from the actual mill are based on projecting the existing accumulation of tailings for the reference 15-year lifetime. The estimates of tailings are given for about 1980; therefore, two years were subtracted from the indicated lifetime. The projected volume after 15 years of operation was then rounded up to account for other wastes. For mills that have already operated longer than the reference life, the present volume of tailings is rounded up to include additional production and other D&D wastes. A density of 1.6 g/cm³ was used.
- b. The reference mill estimate is obtained by multiplying the wastes from the reference mill (Table 4-4) by the mill production capacity. Actual operating times were not used because of increases in the mill capacities at different points in time.
- c. The total is obtained by using the reference mill estimate for mills that have operated under 15 years and the scaled mill estimate for mills that have already operated 15 years.
- d. Mill on standby or shutdown.
- e. Placed on standby before 1980.
- f. Placed on standby, only operated several months, proposed restart in 1984.
- g. Shutdown in 1974 after about 18 years of operation.
- h. There is also a 50 acre inactive pile on the site.
- i. Assumed 500 pCi/g based on Ray Point mill.
- j. The amount of accumulated tailings is unrealistically high and is probably in error. Used 6x10⁶ m³, based on scaling from reference mill, to calculate total.
- k. Planned by United Nuclear, sold to TVA, deferred until 1968.
- l. To be shut down in December 1983, and site to be cleaned.
- m. To be shut down or placed on standby.
- n. Personal communications with Mr. John Linehan, NRC, Denver, CO, January 17, 1983, and Mr. Harry Pettengill, NRC, Washington, D.C., January 18, 1983. The status of the mills has been updated in this final report; however, the estimates for D&D have not been updated since the preparation of the report in early 1982.

been scaled to the actual operating life because the capacity of the older mills has changed significantly and the mills have often operated below capacity. The calculation techniques for the estimates are given in footnotes for the table.

The Ra-226 concentrations shown in Table 4-5 indicate that the past and present ore grade is about 0.2%, considerably greater than the reference value of 0.1% U_3O_8 . Since over 50% of the estimated D&D wastes are already accounted for by the tailings present at the sites (i.e., present volume of tailings is about $100 \times 10^6 \text{ m}^3$ compared to a projected total of $180 \times 10^6 \text{ m}^3$)--Table 4-5, an average ore grade of 0.175%, is used to estimate the activity for the lifespan of these mills. This is based on the present average of 0.2% decreasing to 0.1% and the present existence of over 50% of the final volume of tailings at the sites.

Using an ore grade of 0.175% (equivalent to 500 pCi/g), the total D&D wastes (Table 4-5) of $180 \times 10^6 \text{ m}^3$ will contain about 140 kCi each of Th-230, Ra-226 and other U-238 decay products. Assuming 90% of the uranium was removed by processing, the waste would contain about 14 kCi of U-238.

4.2.1.2. Heap-Leach Facilities

Two heap-leach operations are listed in Table 4-2. The average production of these plants is roughly 100 MT of U_3O_8 per year or twice the U_3O_8 produced by the reference heap-leach facility. Therefore, the D&D wastes of the operating facility are scaled up by a factor of two from the reference heap-leach facility. The results are given in Section 4.2.2.

4.2.1.3. In-Situ Mines

Eleven solution or in-situ mining operations are listed in Table 4-2. Production rates are not indicated, but if the high estimate for 1980 (i.e., as of January 1981) is used, the average production is 173 MT of U_3O_8 per year or almost 80% of the reference plant size (Table 4-4). Given the uncertainties involved, the D&D wastes are scaled directly from the reference facility (see Section 4.2.2 for the results).

4.2.1.4 Uranium By-Product Recovery Facilities

In the U.S. uranium is recovered as a by-product from copper leach liquors and mill tailings, wet process phosphoric acid plants and a beryllium mill (see Table 4-2).

The uranium content of phosphoric acid produced from different phosphate rocks varies from 80 to almost 200 mg/l of U_3O_8 equivalent (Ga81). The best phosphate rock deposits in the U.S. are in Florida and most of the production of uranium from phosphate has been in Florida. The phosphoric acid from Florida, derived by the wet process, contains up to 200 mg/l of U_3O_8 . In 1978 seven companies were in various stages of construction of plants with a total annual production capacity of about 1800 MT (NRC80).

The U.S. Bureau of Mines (Salt Lake City), Kennecott Copper Corporation, and Wyoming Mineral Corporation, a subsidiary of Westinghouse, have developed a process for the recovery of uranium from copper dumps. As a result, Wyoming Mineral Corporation and Kennecott are operating a 65 MT/year commercial uranium recovery operation at Bingham Canyon near

Salt Lake City. Anaconda and Amax have built a similar size facility to recover uranium at Twin Buttes, south of Tucson, Arizona. In addition, Brush-Wellman has built a uranium recovery circuit into its beryllium mill, located near Delta, Utah, to recover 9 to 18 MT of uranium per year (Fa79, NRC80).

The processes for recovery of uranium as a by-product are similar to processes in conventional mills. The uranium is either leached from tailings (i.e., copper tailings) or removed by ion exchange or solvent extraction from liquid process streams. The uranium is then recovered as yellowcake by processes similar to those in a mill.

4.2.2 Existing Contamination

The projected contamination at active facilities at the end of operating lifetime is summarized in Table 4-6. The wastes from uranium by-product operations have not been specifically included in Table 4-6. However, their contribution would be small compared to the other values, since the main source of D&D wastes in milling operations, the tailings, are a result of the parent operation at a uranium by-product recovery plant. The totals for both the volumes and activity in Table 4-6 are dominated by the estimates for the conventional mills.

4.2.3 D&D Alternatives And Waste

The D&D alternatives have been briefly discussed in the reference facility section, Section 4.1, and in the introduction to this chapter. The preferred D&D alternative is basically DECON. SAFSTOR can be used to provide the opportunity for a standby status and later use of the facility,

TABLE 4-6
PROJECTED CONTAMINATION AT URANIUM MILLING FACILITIES

<u>Facility</u>	<u>Number of Facilities</u>	<u>Amount of Tailings or Waste (10⁶ m³)</u>	<u>Activity of Ra-226 (kCi)</u>
Conventional Mills	24 ^a	180	140
Heap-Leach	2	3-4	0.8
In-situ	<u>11</u>	<u>0.04</u>	<u>0.2</u>
TOTAL (Rounded off)		180	140 ^b

- a. One is essentially shutdown, several are on standby and two are being shut down. The estimates do not include one mill that has not operated, two mills that were not operated until after early 1981, and planned mills.
- b. Similar quantities of the other long-lived decay products of uranium are present. About 14 kCi (each) of U-234 and U-238 are also present.

but the radiological half lives of the uranium decay chain nuclides are such that there will be essentially no decay over any reasonable period of time.

Essentially all of the existing contamination and D&D wastes consist of the tailings, or waste materials from milling. Therefore, D&D is achieved by DECON of the process facilities and site, placement of the radioactive material in the tailings pile, and stabilizing the tailings pile. Stabilization of tailings piles has been evaluated by NRC80 and EPA80a. The NRC has specified criteria for stabilizing tailings (NRC80a). Final stabilization plans and criteria will be determined by the standards which EPA is preparing under the authority of Public Law 95-604 (PL78).

It is probable that the D&D wastes from in-situ mining sites may be moved to mills (or heap-leach sites) for final disposition and possible recovery of the residual uranium. This is strongly recommended by NRC80a. The wastes from in-situ operations, based on the amount of uranium produced, represent much smaller volumes than those from conventional mills or heap-leach operations, making it feasible to move the wastes.

4.2.3.1 Volume and Activity

The volume and activity of D&D wastes are essentially the same as the existing contamination summarized in Table 4-6. The total volume and activity of D&D wastes are $180 \times 10^6 \text{ m}^3$ and 140 kCi of Ra-226, respectively, along with similar amounts of the other long-lived decay products of uranium. Both the volume and activity are all essentially due to conventional mills. The wastes from by-product recovery of uranium are not included since these wastes basically are due to the parent operation and

have properties similar to those of the much larger volumes of waste from the parent operation.

4.2.3.2 Chemical and Physical Form

The D&D waste materials are residual soil and rock materials from the ore. For conventional mills they are the sands and slimes resulting from grinding and leaching the ore. For heap-leaching the wastes are the coarser grained ore material. For in-situ mining most of the waste is calcite. Contaminated soils will also be included.

For about 80% of the conventional mills and most heap-leach operations the material will have a pH of 1 to 3 from residual acid from acid leaching. For the other operations the pH will be greater than 7 from carbonate or alkaline leach operations.

4.2.3.3 Materials

As previously noted, the controlling volumes are the remaining material from the ore (calcine from in-situ leach) and contaminated soil. Lesser amounts of process and building materials will also be included; however, most process equipment and the majority of the facilities can be decontaminated.

4.2.3.4 Residual Material

Most of the process equipment and the major fraction of the buildings can be decontaminated for uncontrolled release. What actually happens will depend on the further need for the equipment and the facilities at the time of the D&D.

5. URANIUM HEXAFLUORIDE CONVERSION FACILITIES

Uranium conversion facilities receive uranium concentrate from mills, remove impurities, and convert the uranium to UF_6 , the feed material for the U.S. gaseous enrichment plants. There are only two commercial conversion plants operating in the U.S.: the Allied Chemical Plant in Metropolis, IL., and Kerr-McGee Plant, in Sequoyah County, Gore, OK. There is also a small DOE plant at the Portsmouth, OH, gaseous diffusion plant for processing scrap and waste materials. There are five other DOE facilities and a commercial facility that have been shut down. These facilities are listed in Table 5-1.

The two operating commercial plants use different processes. The basic difference is the phase of the operation and process for removing impurities from the uranium.

The Kerr-McGee plant uses the conventional wet solvent-extraction process to purify the uranium at the head end of the system. The first step of the process is dissolution of the feed material in nitric acid. The uranyl nitrate is separated from metallic impurities in the dissolver solution by solvent extraction, usually tributyl phosphate (TBP) dissolved in an inert hydrocarbon. The purified uranyl nitrate is concentrated by evaporation in a boil-down tank and converted to UO_3 (orange oxide) by denitration. The uranium is subsequently reduced to UO_2 (brown oxide) and converted to UF_4 (green salt) and UF_6 by hydrofluorination and fluorination, respectively. The impurities are removed as liquid waste in the solvent extraction process.

The wet process has several advantages in that it can accept different

TABLE 5-1
URANIUM HEXAFLUORIDE CONVERSION PLANTS
Source: E181

<u>Plant Operator</u>	<u>Location</u>	<u>Present Status</u>
Allied Chemical	Metropolis, IL	Operating
Babcock and Wilcox ^a	Apollo, PA	Shut Down
Kerr-McGee	Sequoyah County, OK	Operating
Mallinckrodt Chemical--DOE	Weldon Spring, MI	Shut Down
National Lead of Ohio--DOE	Fernald, OH	Shut Down
Goodyear Atomic--DOE ^b	Portsmouth, OH	Shut Down
Union Carbide--DOE	Oak Ridge, TN	Shut Down
Union Carbide--DOE	Paducah, KY	Shut Down

^a Formerly Nuclear Materials and Equipment Corp. (NUMEC.).

^b The large hexafluoride conversion plant was put into safe storage in the 1961-62 period. It has since been converted to another use. There is currently a small hexafluoride plant for converting returned and reclaimed uranium compounds to feed for the Cascade Enrichment Plant.

chemical and physical forms of feed product, and it can produce purified uranium as an oxide, metal, UF_4 or UF_6 (Be81). The liquid waste, which is discharged to on-site lagoons, may be a disadvantage.

In the Allied Chemical process, termed dry hydrofluorination, the purification takes place at the end of the process. The basic steps are roasting the feed to produce UO_3 , reduction to UO_2 and conversion to UF_6 . The process is designed for feed consisting of ammonium diuranate (yellowcake) or uranium oxide. Feed containing high concentrations of sodium or magnesium requires additional processing. Furthermore, yellowcake slurry cannot be used as feed since the first step is roasting rather than dissolution. Another disadvantage is that the only purified uranium product is UF_6 . An advantage is that the impurities are produced as a solid waste (Be81).

Although several conversion facilities have been shut down, no facilities have been fully decommissioned. A large facility at Portsmouth, Ohio, was shut down and then converted to another use, but there is no published information on this operation (E181). The U.S. Army started decommissioning the former Mallinckrodt Plant at Weldon Spring, MO., but abandoned the effort (E181, DOE80b).

Reference conversion facilities and scenarios for D&D of the facilities have been developed by E181 and NRC81. A D&D plan has been developed for the Weldon Spring facility, but this plan was not available. The Weldon Spring plan is the basis of the plan proposed by E181. Also, E181 notes that the experience from decommissioning fuel fabrication plants is pertinent and helps demonstrate the feasibility of D&D of conversion facilities.

The operating lifetime for the two active commercial plants is estimated to be about 40 years. Although the six inactive plants each operated less than about thirty years, their operating lifetime was primarily based on program needs (five were DOE facilities), not operational capability.

5.1 REFERENCE URANIUM HEXAFLUORIDE CONVERSION FACILITIES

Reference conversion facilities are defined by E181, NRC81, DOE80a, and EPA73. Elder (E181) and NRC81 use a 10,000 MTU/year wet solvent extraction (WSE) plant as the reference facility. EPA73 used a 5,000 MTU/year WSE plant. DOE80a proposed a dual process plant with a capacity of 5,000 MTU/year by WSE and 5,000 MTU/year by dry hydrofluorination (DHF). The reference facility for this section is based on the 10,000 MTU/year WSE facility proposed by E181. This facility is similar to the Kerr-McGee 9,000 MTU/year plant (DOE80a), but not specifically patterned after it.

The reference facility is based on a summary of the information from E181. Although a reference site, climatology and waste effluents are developed by E181, they have minimal impact on D&D and are not summarized here.

The reference facility is located on a 4.7 km² site in the midwest. The facility receives feed material from many of the mills in the western U.S. The parameters for the reference facility are summarized in Table 5-2.

5.1.1 Description of Facility

The uranium concentrate, yellowcake or uranium oxide, is received in

TABLE 5-2
REFERENCE URANIUM HEXAFLUORIDE CONVERSION FACILITY

<u>Item</u>	<u>Parameter</u>
Facility Size	10,000 MTU/year
Site Size	4.7 km ²
Inner Site	30.4 ha
Operational Buildings	
Main Process Building (Ground area 5,500 m ²)	7,400 m ²
Solvent Extraction Building	370 m ²
Warehouse and Other Buildings	3,380 m ²
Total Floor Space	11,150 m ²
Facility Inventory of Uranium	
At Shutdown	105,000 kg U
After Inventory Clearout	
Waste Lagoons	36,900 kg U
Process Equipment	9,200 kg U
In Buildings and Ventilation System	3,200 kg U
Total After Inventory Cleanout	49,300 kg U

0.21 m³ (55 gal) drums and is transferred to a sampling system. The sampling system removes 0.1% of the feed for accounting purposes. The main stream is conveyed either to a redrumming station or to storage hoppers in the digestion area.

Figure 5-1 is a flow diagram for the plant processes. Subsequent to sampling, the uranium concentrate feed is dissolved in hot 40% nitric acid to form $\text{UO}_2(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (Step b of Figure 5-1). The solution contains about 400 g of uranium per liter (Be81). Next, the uranyl nitrate solution is purified by solvent extraction. Basically, the aqueous mixture is fed to a series of pumper-decanter mixer-settlers, where purified uranyl nitrate is extracted by countercurrent flow of TBP in normal hexane (Step c of Figure 5-1). The flow ratio of the organic solvent is 13 times that of the aqueous stream. The raffinate leaving the last stage contains less than 0.1 g of uranium per liter. The raffinate waste stream, which contains most of the radioactive impurities from the feed (i.e., Th-230 and Ra-226) is neutralized with lime and is discharged to a waste lagoon on site or returned to the uranium mills for disposal. After additional purification by counter-current scrubbing, the uranyl nitrate solution is concentrated in an evaporator and a boil-down tank.

The concentrated solution, which contains about 1.2 kg of uranium per liter, is then decomposed in a trough-type denitrator or calciner to uranium trioxide, oxides of nitrogen and nitric acid vapor (Step d, Figure 5-1).

The uranium trioxide is then contacted with cracked ammonia gas ($3\text{H}_2:\text{N}_2$) at about 590°C in fluid bed reactors (step e in Figure 5-1) to reduce it to uranium dioxide (Be81). The gaseous releases from this

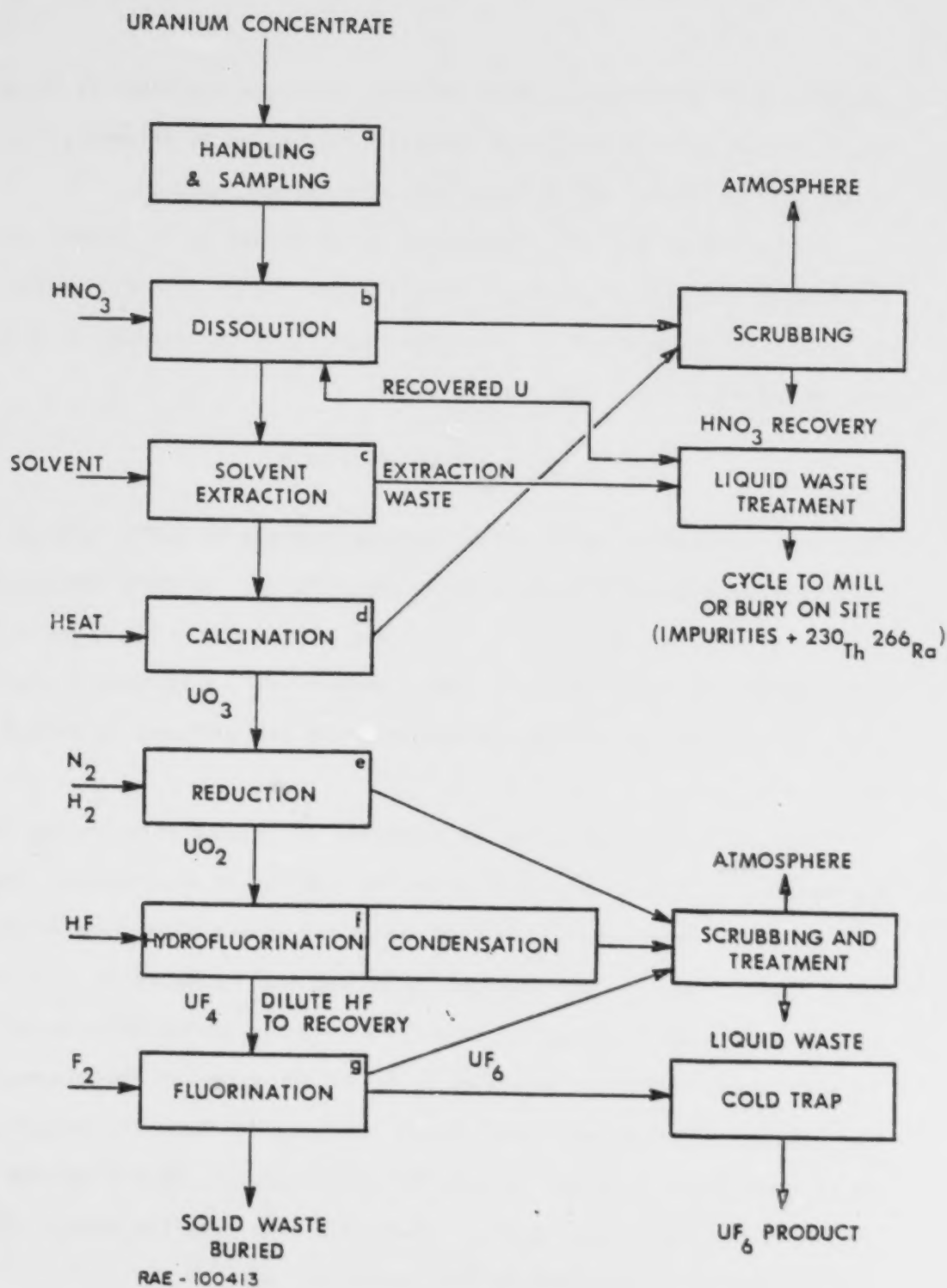


FIGURE 5-1. UF₆ PRODUCTION - WET SOLVENT EXTRACTION

Source: E181

process are filtered and scrubbed prior to discharge (hydrogen is burned). The reduction conditions must be carefully controlled to prevent sintering of the uranium oxides, which interferes with the next process.

The purified uranium dioxide may be withdrawn as a product or it proceeds to the hydrofluorinator (Step f Figure 5-1). The uranium dioxide is reacted with anhydrous HF in a two-stage fluid bed reactor to product uranium tetrafluoride. The reaction is:



This is an exothermic reaction that proceeds rapidly at 500°C. However, at 500°C the equilibrium mixture contains about 35% HF. At 300°C the reaction rate is slower, but more of the HF is used. By using a two-stage system with reactors at both 500°C and 300°C, respectively, a reasonable reaction rate is obtained and the HF concentration in the effluent is reduced to 15%.

The uranium tetrafluoride is converted to uranium hexafluoride (UF₆) by reacting it with elemental fluorine in a series of fluorination towers. The solid UF₄ reacts rapidly with fluorine gas with a flame temperature of about 1600°C (Be81). The UF₆ gas is cooled and condensed in cold traps (about -10°C, Be81) to a solid. The UF₆ is removed periodically by melting it with steam (64°C) and draining it to 9.1 MT cylinders for shipment to the gaseous diffusion enrichment plants (E181). The final UF₆ product must be at least 99.5% by weight to meet DOE specifications for the gaseous diffusion enrichment plants (Be81). There are also detailed specifications for the content of other metals and impurities.

In addition to the previously mentioned basic processes, there are

numerous process loops for recycling partially reacted materials, recycling materials (e.g., HF, nitric acid and TBP) and processing effluent streams.

There are four basic waste effluent sources. These are:

- Scrubbers and other air cleaning equipment for the dissolution and calcination processes.
- Scrubbing and other air cleaning equipment for the reduction, hydrofluorination, and fluorination processes.
- A liquid waste system for the radioactive impurities removed in the solvent extraction process (also some waste from dissolution).
- Liquid waste primarily from the hydrofluorination system gas scrubber and fluorination process (minimal radioactivity).

Most of the radioactive waste is associated with the waste from the solvent extraction process. The primary radioactive contaminants in uranium concentrate are Th-230 and Ra-226. The concentrations are different for the acid leach and carbonate leach milling processes. Since most mills use the acid leach process, the values for tailings produced by the acid leach process are used (acid leaching transfers more Th-230 than carbonate leaching).

The process equipment for the reference facility is housed in two buildings. Most of the activities are located in the main building, which covers 5,500 m² of ground area and has 7,400 m² of floor space. The solvent extraction building has 370 m² of floor space.

The main building is built of concrete block and has concrete floors. There is sheet metal siding in the process areas. The floors in the process areas are sealed, and there is some steel plating.

The solvent extraction building is steel-frame construction with steel

siding. The floor is sealed concrete. The yellowcake slurry and solvent extraction activities are conducted in this building.

The plant ventilation system provides for a minimum of 6 air changes per hour (ach) in process areas, with 10 ach in most areas. There are 12 ach in the solvent extraction process areas.

The Allied Chemical plant dry hydrofluorination process converts uranium concentrate feed to UF_6 without the solvent extraction purification process. The other process steps are similar to those previously discussed, except that the UF_4 to UF_6 conversion takes place at a lower temperature, about $500^{\circ}C$, in an air-cooled fluid-bed reactor. The UF_6 contains fluoride impurities with a range of boiling points (e.g., HF , TeF_6 , MoF_6 , MoF_4 , VOF_3) and nonvolatile fluorides of radium and thorium. A two stage distillation purification process is needed to purify the UF_6 because of the range of boiling points of the impurities. The radium and thorium remain in the bottoms of the distillation columns (Be81).

Estimates of the amount of Ra-226 and Th-230 transferred from the ore to yellowcake, in the milling process, vary. Recent data from several mills indicate that less than 1% of the thorium and radium are transferred (Fo80, Mo79). Some previous estimates range from one to several percent (e.g., Be81). The values for the reference mill, based on E181, are 0.003 mCi of Th-230 and 0.0003 mCi Ra-226 per kilogram of uranium feed material. These values are equivalent to a 1% transfer of Th-230 and 0.1% transfer of Ra-226, which agrees with the data from Fo80 and Mo79.

Normal operation of the facility produces a variety of solid, liquid, and airborne wastes. Although the airborne releases result in some deposition of radioactivity on the site, the accumulated activity will not

require D&D. Estimates from E181 indicate the accumulated deposition from 40 years of operation would be 1 pCi/g of U-238 for the surface 5 cm of soil. The concentrations of Ra-226 and Th-230 would be much lower. These values are below applicable standards and guides (EPA77, EPA80).

Liquid wastes are discharged to the solvent extraction lagoons and the fluoride waste lagoons. These lagoons are included in the D&D program.

Packaged and solid wastes are shipped off site for disposal. However, some solid wastes are disposed of on site in the fluoride lagoons or by burial. These wastes are considered in the D&D estimates.

After shutdown and before final inventory cleanout, the uranium inventory of the reference facility is estimated to be 105,000 kg of uranium. This includes the wastes in the lagoons, ash in the fluorination tower, scrap, scrap solutions, residuals of process solution, and visible contamination. Final cleanout is a process that is done periodically between processing campaigns. This operational cleanout is considered to be part of plant operations, not decommissioning.

Final cleanout includes removal of unneeded process chemicals, removal of all uranium products, vacuuming and brushing contaminated surfaces, disposition of scrap materials, removal of sludge from UF₆ and HF scrubbers, and flushing of the process equipment (generally three times). The solid and liquid wastes from this cleanup are processed prior to decommissioning.

After completion of final inventory cleanout, D&D operations commence. For this section, D&D will be limited to DECON. Because of the long half lives of the materials involved, SAFSTOR would only delay the need for DECON and the final job would be the same, if not worse, because of

additional corrosion and the absence of personnel familiar with the facility.

The first operational D&D activity is additional flushing and chemical decontamination of all process equipment and piping. This includes: spray cleaning, hot corrosive acid flushing, and hand wiping of dry processing equipment. Because of the minimal gamma activity from uranium, these and subsequent operations can generally be done as a hands-on operation.

Specific items of process equipment, shipping volumes, and levels of contamination are given in Appendix C. The estimates in Appendix C include volumes of both unrestricted waste and radioactive LLW. Wastes from process equipment; pipes, conduit, ducts, and light fixtures and cable trays; and concrete rubble are listed separately for the different process categories. The estimates from Appendix C are summarized in Table 5-3.

The estimates from Table 5-3 indicate the total D&D wastes from the process equipment and facilities result in 1,300 m³ of LLW containing about 2,700 kg of uranium. There are also 1,400 m³ of unrestricted commercial waste. These estimates do not include the waste lagoons and items recycled for general use.

The reference facility has four solvent extraction waste lagoons and two fluoride waste lagoons. The fluoride lagoons are considerably smaller than the solvent extraction lagoons and contain much less uranium and essentially no other radioactivity. There are about 5,700 m³ of sludge in the fluoride lagoons, containing about 2,500 kg of uranium (E181). This equates to a concentration of 0.44 kg/m³. Assuming a density of 3 g/cm³ (e.g., CaF₂) and an activity of 0.33 microcurie of U-238 per gram of uranium, this equates to about 50 pCi of U-238 per gram of sludge. This is

TABLE 5-3

D&D WASTES FROM REFERENCE URANIUM CONVERSION FACILITY

Location or Process	Wastes From Process Equipment		Wastes From Buildings and Facilities	
	Unrestricted Waste (m ³)	Restricted Waste, LLW (m ³)	Unrestricted Waste (m ³)	Restricted Waste, LLW (m ³)
Sampling Station and Feed Receiving	110	66	94	29
Dissolution and Solvent Extraction	130	21	120	100
Uranyl Nitrate Concentrator	49	13	75	68
Denitration	31	58	50	29
Reduction (UO ₃ to UO ₂) and Hydrofluorination	200	140	--	90
Fluorination	50	180	--	7
Analytical Laboratory	62	-- ^c	72	9
Fluoride Generation	90	190	--	--
UF ₆ Cylinder Loading	15	24	21	5
Other Support Areas ^b	180	240	42	10
TOTAL (Rounded Off)	920	930	470	350

^a Summary of information from Appendix C, essentially all of the uranium is associated with the process equipment.

^b The temporary radioactive waste facility contributes over half of these wastes.

^c Minor contribution.

about 50 times natural background, but similar to some suggestions for acceptable levels of uranium contamination (E181, He79). Most of the material in the fluoride ponds is calcium fluoride (precipitated by use of lime), with some calcium hydroxide and calcium carbonate. The uranium is probably present as a fluoride.

The solvent extraction waste (SEW) lagoons contain about 21,600 m³ of sludge containing about 0.28% (weight) uranium (E181). Assuming a density of 1.6 g/cm³ for the dry sludge indicates an inventory of 97,000 kg of uranium. This is almost three times the inventory of 34,400 kg of uranium reported by E181. Apparently, the volume of 21,600 m³ is not all sludge, but also includes the pond liner and contaminated soil.

The SEW lagoons are assumed to contain 21,600 m³ of waste which contains 34,400 kg of uranium. The average uranium content is thus about 0.1%. This is equivalent to the grade of many ores that are mined, and it may be cost effective to return the SEW to a uranium mill for reprocessing.

The SEW lagoon will also contain about 1000 Ci of Th-230 and about 100 Ci of Ra-226, assuming all of the impurities from the feed material have been accumulated in the lagoons. These estimates are based on the reference plant size of 10,000 MTU/year, an operating lifetime of 40 years, and the previous estimates in E181 of 0.003 mCi/kg and 0.0003 mCi/kg for Th-230 and Ra-226, respectively, in the feed material. Assuming this activity is averaged throughout the lagoon material, the concentrations are 30,000 pCi/g and 3,000 pCi/g for Th-230 and Ra-226, respectively. These concentrations are considerably greater than the values for most uranium mill tailings.

The existing contamination and waste estimates for D&D of the

reference facility are summarized in Table 5-4. Recycled equipment, which is not included in the waste values, is listed in a footnote (equivalent to about 100 m³).

The waste lagoons account for both the major fraction of the volume and the activity of the radioactive (LLW) wastes. Although there is some uncertainty as to whether the fluoride lagoon will have to be moved or whether it can be stabilized in place, it has been added into the totals.

5.2 ACTIVE COMMERCIAL URANIUM HEXAFLUORIDE CONVERSION FACILITIES

5.2.1 Description Of Facilities

There are two operating commercial facilities: Kerr-McGee in Sequoyah County, OK, and Allied Chemical in Metropolis, IL. The Kerr-McGee facility is a 9,000 MTU/year wet process facility similar to the reference facility. The Allied facility is a dry hydrofluorination facility with a capacity of 14,000 MTU/year. Although the Allied plant differs somewhat from the reference facility (e.g., dry versus wet process, and 40% larger), the reference plant is believed to provide a reasonable characterization of the D&D wastes. It is possible that both the volume and uranium content of operational wastes from purifying the uranium may be smaller for the dry process than for the reference wet process. However, firm information verifying this is not available, and this will be offset by the larger facility size.

5.2.2 Existing Contamination

Estimates of existing contamination at commercial facilities are given

TABLE 5-4

SUMMARY OF WASTES FROM REFERENCE URANIUM HEXAFLUORIDE CONVERSION FACILITY

Source Of Wastes	Unrestricted Wastes (m ³)	Restricted Radioactivity Wastes, LLW	
		Volume (m ³)	Radioactivity (kg U or Ci)
Process Equipment	920	930	2,700 kg U
Facilities (Buildings)	470	350	---
Recycled Equipment ^a	-	-	-
Waste Lagoons			
Solvent Extraction Wastes		21,600	34,400 kg U 1,000 Ci Th-230 100 Ci Ra-226
Fluoride		5,700	2,500 kg U
Subtotal of Wastes from Process Equipment & Facilities	1400	1,300	2,700 kg U
Total Wastes	1400	29,000	40,000 Kg U 1,000 Ci Th-230 100 Ci Ra-226

^a Recycled items include a forklift and shelving from the sampling area (35m³); uranium scanners and packaging equipment from the incinerator (7m³); equipment from the laboratory; instrumentation, shelves, and tables from the decontamination, laundry, and change rooms (roughly 20 m³); and test equipment, parts, benches, etc. from the instrument repair shop (about 25 m³).

in Table 5-5. These values are based on estimates for the reference facility from Tables 5-3 and 5-4.

About 105,000 kg of uranium are projected to be in the facilities at the time of shutdown, with an additional 37,000 kg of uranium in the waste lagoons. It is also estimated that there will be 1000 Ci of Th-230 and 100 Ci of Ra-226 in the solvent extraction waste (SEW) lagoon. The Ra-226 concentration in the SEW lagoon wastes is estimated to be 3,000 pCi/g.

Most of the uranium in the facility, almost 90,000 kg, is expected to be removed and recovered during the final inventory cleanout, which occurs prior to D&D.

5.2.3 D&D Alternatives and Wastes

5.2.3.1 Volume and Activity

Estimates of the D&D wastes are given in Table 5-5. Estimates of the unrestricted waste are given in the footnotes.

The alternatives for D&D are discussed in Chapter 2. Because of the long half lives of the radionuclides, DECON is essentially the only pertinent alternative. SAFSTOR could be used to delay D&D; however, the use of SAFSTOR with the eventual need for DECON would cost more than DECON directly after shutdown. The wastes would be the same if not more, for delayed DECON as for immediate DECON. However, SAFSTOR could be used to give an alternative to reactivate the facility at a later time.

5.2.3.2. Chemical and Physical Form

The uranium contamination in the facilities and lagoons will include

TABLE 5-5

EXISTING CONTAMINATION AND D&D WASTES AT COMMERCIAL
URANIUM HEXAFLUORIDE CONVERSION FACILITIES^a

Item	Kerr-McGee		Allied Chemical		Totals	
	Volume (m ³)	Activity (kg of U or Cf)	Volume (m ³)	Activity (kg of U or Cf)	Volume (m ³)	Activity (kg of U or Cf)
Existing Contamination (at Shutdown)	--C	105,000	--	105,000	--	210,000
Contamination After Inventory Cleanup						
Process Equipment Facilities (Buildings)	--	9,200	--	9,200		18,000
Waste Lagoons	27,000	37,000	27,000	37,000		6,400
						74,000
Wastes From D&D						
Process Equipment Facilities	930	2,700	930	2,700	1,900	5,400
Waste Lagoons	350	--	350	--	700	--
	27,000	37,000	27,000	37,000	54,000	74,000
Total Restricted Radioactive (LLW) Wastes ^a	28,300	39,700	28,300	39,700	57,000	69,000
Unrestricted Wastes ^b						

^a Values are rounded off.

^b Unrestricted nonradioactive waste, 1,400 m³ per facility--total of 2,800 m³ for both facilities. Also about 100 m³ of recycled equipment, etc., from each facility.

^c Not pertinent.

uranium diuranate, uranium oxides (both valance 4 and 6), and uranium fluorides. Essentially all of the Ra-226 will be in the solvent extraction waste (SEW) lagoon in the form of barium radium sulfate (e.g., the waste is neutralized with ammonia and radium is precipitated with barium sulfate).

Most of the uranium feed is uranium diuranate. Therefore most of the contamination prior to dissolution will be uranium diuranate (soluble). In the dissolution and solvent extraction areas the uranium will primarily be as uranium nitrate with some uranium oxide. The uranium in the SEW lagoon is also expected to be as a nitrate or oxide.

The uranium contamination will be as an oxide in the denitration and reducing areas, and as an oxide or a fluoride in the fluorination areas. During denitration uranium trioxide, which is fairly soluble, is formed. This is reduced to uranium dioxide, which is insoluble.

In the hydrofluorination and fluorination areas, uranium contamination will be primarily UF_4 , with some UF_6 and unconverted UO_2 . The uranium in the fluoride waste pond is expected to be primarily UF_4 , with some uranium oxides. Uranium hexafluoride reacts with moisture and is hydrolyzed.

5.2.3.3. Materials

The D&D wastes include process equipment, pipe, conduit, concrete rubble, and building materials. The relative amounts of the various materials are summarized in Table 5-5. Additional details are given in Appendix C.

5.2.3.4. Residual Materials

Most of the structural facilities are postulated to be left intact;

however about 100 m³ of concrete rubble is generated from decontamination of about 2400 m² of floor area. Other material which is assumed to be recycled and used in its original form includes a forklift, benches, tables, cabinets, and instrumentation (about 100 m³). It is estimated that there will be about 1400 m³ of decontaminated waste for commercial disposal. This will include tanks and a large amount of pipe. Depending on the economics, much of this could be recycled as scrap.

5.3 OTHER URANIUM HEXAFLUORIDE FACILITIES

Table 5-1 lists a small active DOE facility at Portsmouth, OH, an inactive commercial facility owned by Babcock and Wilcox, and five inactive government facilities, one of which (Portsmouth) has been converted to another use.

In 1956, the Atomic Energy Commission acquired a 1 km² site at Weldon Spring, Missouri, from the U.S. Army. Mallinckrodt Chemical Corp. operated a uranium conversion facility at the site until 1966. After the plant was shut down the Army reacquired the plant facilities and land (excluding 20 ha raffinate pit area and a nearby quarry) with the intent of using them for a herbicide orange production plant (DOE80b). However, the project was never implemented and the Army declared the property excess in 1970 (DOE80b). The Army started to decontaminate the buildings in 1967, but abandoned the effort in 1969 (E181).

The DOE has responsibility for the 20 ha raffinate pit area adjoining the plant site, and a 3.2 ha quarry where wastes were placed. These sites are part of the DOE Surplus Facilities Management Program (SFMP) (DOE81 and

DOE82a).

The future of the Weldon Spring facilities is uncertain. The Army attempted to surplus them in 1970, but the Government Services Administration determined that they could not be released because of the existing contamination. The facility is under the control of the Army, but the Army has requested that the DOE take over the 68 ha site (DOE80b). A site map from DOE81 indicates the buildings on the site cover an area of roughly 10 ha.

It is assumed that the existing contamination and facility D&D wastes will be similar to those estimated for the reference facility. Although the facility may have had a lower production rate than the reference facility, various types of operations and older equipment could result in similar or greater waste volumes.

Wastes from this site are not included in the summation of wastes for the uranium fuel cycle.

DOE Conversion Facilities--There are inactive DOE conversion facilities at Fernald, OH (National Lead of Ohio Feed Materials Production Facility); Oak Ridge, TN, and Paducah, KY (Union Carbide Gaseous Diffusion Plants); and Portsmouth, OH (Goodyear Atomic Gaseous Diffusion Plant). There is also an active small conversion plant at Portsmouth. The facilities at Oak Ridge and Paducah were fairly large, and it is assumed that the facility contamination and D&D wastes will be equal to those of the reference facility. However, the wastes in the lagoons will be about one-half of the reference facility estimates (Tables 5-4 and 5-5) since the plants only operated for a fraction of the reference 40-year period.

The inactive facility at Portsmouth is not considered since it has

been converted to another use.

There is little quantitative information on the small active facility at Portsmouth. Information in ERDA77 indicates the conversion plant may cover roughly 200 to 400 m² of floor space. The facility is primarily for recovering UF₆ from scrap and wastes. It is estimated that the D&D wastes will be one-tenth, or less of the values for the reference facility.

The Feed Materials Production Center at Fernald includes many activities similar to the processes in uranium conversion. Available information indicates that the specific inactive conversion facility was much smaller than the reference facility (Be82, NL78). It is estimated that D&D wastes for the inactive facility at Fernald would be roughly one-fifth of those for the reference facility. Because of the short operating time, the lagoon wastes are estimated to be one-tenth of the reference wastes.

It is assumed that the inactive Babcock and Wilcox plant in Apollo, PA (formerly owned by Nuclear Materials and Equipment Corp.), was similar in size to the Fernald plant.

Since most of these inactive plants were DOE facilities, the estimates of D&D wastes are not added to the estimates for the uranium fuel cycle.

6. URANIUM ENRICHMENT

Although some reactors, such as the CANDU type can operate with natural uranium, most reactor designs require uranium enriched in U-235 or other fissile material (e.g., plutonium). The U.S. developed uranium enrichment technology and capacity for nuclear weapons production, but the production capability is now primarily used for power reactors. Enriched uranium is also needed for Navy ship reactors, test and research reactors, and plutonium production reactors. Light water reactors (LWR) require an enrichment of about 2 to 4% U-235; whereas Navy submarine reactors require enrichment of up to 90% or more.

The three U.S. gaseous diffusion enrichment (GDE) plants at Oak Ridge, Tennessee, Paducah, Kentucky, and Portsmouth, Ohio produce various grades of enriched uranium for U.S. national defense, research and commercial uses and for export to other countries. The gaseous enrichment plants are owned by the DOE and operated under DOE contracts. DOE is also building a centrifugal enrichment plant on a site adjoining the Portsmouth plant which is scheduled for full operation around 1990.

This report is limited to the nuclear fuel cycle; therefore the enrichment plants will be evaluated from the standpoint of the fuel cycle. Since the plants produce numerous grades of enriched uranium, the contamination will encompass all grades of enriched uranium.

The GDE plants have been operating since the mid 1940s (Oak Ridge) and 1950s (Paducah and Portsmouth). However, during that period, and especially during the late 1970s, they have undergone updating and changes. The first cascades built at Oak Ridge in 1945 and 1946 have been shut down,

but the facility is still operating. The expected operating lifetimes are about 40 years, and longer with updating. The DOE (ERDA76) uses an expected operating lifetime of 30 years for future plants. Depending on the requirements for enriched uranium and the success of the centrifugal plant, the existing GDE plants could be phased out in 10 to 20 years. Centrifugal plants will require a large capital outlay, but will have much lower operating costs (i.e., use less power) (Vi79).

There is little if any D&D experience with enrichment plants. Several sections of the Oak Ridge facility have been shut down (K-25 and K-27), but it is not known whether there has been any D&D. The alternatives and procedures for D&D of gaseous diffusion plants will be comparable to those for uranium fuel fabrication plants and other similar facilities. No unforeseen problems are expected and existing technology is sufficient (ERDA76, ERDA77). Given the volumes of low-level radioactive waste (LLW) buried on the sites, LLW burial grounds may be left on the sites.

6.1 URANIUM ENRICHMENT FACILITIES

There is only limited information available on the three GDE plants operating in the U.S. and essentially none on the centrifugal plant. Since the centrifuge plant will not be in full operation for about ten years, and the construction of the basic enrichment equipment has not even begun, it will not be discussed.

Although reference facilities have been developed for enrichment plants (EPA73, ERDA76, DOE80a) the information is not pertinent to estimating wastes for D&D. Therefore, the D&D wastes for enrichment plants

will be estimated by using a combination of scaling factors from uranium fuel fabrication facilities and estimates of the surface area of the process equipment.

6.1.1 Description of Facilities

Gaseous diffusion technology uses the preferential diffusion of the U-235 atoms (versus the larger undesired U-238 atoms) through complex porous barriers. The principal of the technique is molecular diffusion. In a closed cell at thermal equilibrium, all molecules of a gas mixture have the same mean kinetic energy. Therefore, the lighter molecules (U-235) travel faster and strike the cell walls more frequently than the heavier molecules (U-238). Properly sized holes, too small to allow the flow of the gas as a whole, will allow passage of a larger proportion of light molecules in relation to their concentration than of the heavy molecules (Vi79, Be81). The only workable chemical compound of uranium is UF_6 which is a solid at room temperature but a gas at about 60° C. The gaseous diffusion process is based on the separation factor that is accomplished in each stage. This factor is the relative enrichment of U-235 accomplished in each stage. The ideal elementary separation factor for the natural isotopic mixture of U-235 and U-238 in uranium hexafluoride is 1.00429. This ideal factor is reduced by the non-ideal features of operating systems (Vi79). Consequently, it takes over 1200 stages to produce an enrichment of 3% U-235 (ERDA75).

The basic components of an enrichment plant are: heaters or steam systems to vaporize the UF_6 , diffusers which contain the barriers, compressors and motors to provide operating pressure and transport of

material, piping and control valves to transmit the UF_6 streams between diffuser stages, coolers to remove heat resulting from compression of gaseous UF_6 , input and loading equipment to charge the system and remove enriched and depleted product, and storage tanks to evacuate UF_6 from the system for maintenance or emergency shutdown. Since UF_6 is a solid at room temperature, facilities must be available to evacuate it from the diffusion stages in the event of loss of power or operational problems to keep it from plating out and plugging the systems (Vi79).

The diffusion stages, the basic elements in the process, are constructed somewhat like tube-type heat exchangers and are packaged in cells, the basic grouping of stages that can be isolated by valves and bypass lines. Identical stages are then grouped as cascades; a plant is composed of one or more cascades. Cells are composed of 5 to 20 stages. The stages are produced in various sizes. The largest stages at the Portsmouth plant are in nickel plated diffusers which are 5.8 m long and 3.4 m in diameter. The barrier tubes, the diffusion material or barrier, for the large stages are 2.75 m long (Vi79).

Various size pumps and compressors are used. The motors are larger than most industrial motors (ERDA76) and range up to 3000 kw (over 3000 hp) or more for the upgraded units.

The Paducah and Oak Ridge plants are operated by Union Carbide Co. for DOE; however, Union Carbide has announced plans to withdraw as operating contractor by the mid 1980s. The Portsmouth plant is operated by Goodyear Atomic Co. All three plants are similar in size (ERDA75). Although the plants could be operated separately, due to somewhat different features the overall efficiency is increased by operating them as a

complex. The independent operation would result in a 1% loss of capacity (Vi79, DOE81c). The plants trade product and tails to increase the operation efficiency. For example, although the Paducah plant can produce a product of 5% enrichment, the enrichment is limited to 1% when operated in conjunction with the other plants. Operating at a lower enrichment allows production of more material. Paducah produces enriched feed for Oak Ridge and Portsmouth and may process tails from these plants to recover additional U-235 (Vi79).

The sizing and production of enrichment plants is given in terms of separation work units (SWU) per year, where the SWU has units of kilograms or metric tons of uranium. The SWU, the energy per unit mass of enriched material, is a complex unit which is not subject to a simple calculation. It includes the quantities of materials and enrichments of the input, product, and tails. One SWU represents a specific increment of system operation. For example, 1-MT SWU will produce 1 MT of 1.37% enriched uranium from 2.3 MT of natural uranium, with 1.3 MT of tails at 0.2%. One MT SWU will also produce 0.0039 MT of 93% enriched uranium from 0.73 MT of natural uranium (0.2% tails) (Be81, Vi79).

Although the Oak Ridge facility originally had 5104 separation stages and could produce 97.65% U-235, part of the facility has been shut down. Portsmouth is now the only facility with the operational capacity to produce 97.65% U-235 (Vi79).

The three plant complex had a combined capacity of 17,000 MT SWU around 1977. This will be raised to about 27,000 SWU by 1985 as a result of the Cascade Improvement Program (CIP) and Cascade Upgrading Program (CUP). The CIP includes the installation of advanced barriers and

compressors. Barrier improvements have increased productivity by about 22 times since the early Oak Ridge facility was built. The CUP program will take advantage of the improved barriers and compressors by increasing the power of the associated motors. These improvements should have only minimal impact on D&D since the same basic facilities are being used (Vi79). The improvements will result in greater production from a given power level and will also increase the power level of the facilities (Vi79,DOE81c).

Table 6-1 provides a summary of information on the plants. The area per stage for different parts of the plants is similar for each plant. Six different sizes of stages are used in the Portsmouth plant to balance the flow. The purge stages (remove contaminating gases) and other smaller stages are in building X-326. Intermediate stages are in building X-330 and two larger stages are used in building X-333 (Vi79).

6.1.2 Existing Contamination

There is very little information on the existing contamination at GDE plants and on the production and disposal of wastes on site. Estimates are made by applying information from the reference fuel fabrication plant and the available information on waste disposal.

Table 6-2 summarizes information from NRC79 and several other sources on waste disposal at the sites. (Information in ERDA77 indicates that several waste lagoons are not included in the estimates in Table 6-2). The differences in waste estimates for the facilities may be due to incomplete reporting, but is probably due to differences in facility operations. The higher curie content for the Paducah facility may be due to processing

TABLE 6-1

FEATURES OF GASEOUS DIFFUSION ENRICHMENT PLANTS
SOURCE: V179

<u>Facility</u>	<u>Building</u>	<u>Number of Stages</u>	<u>Building Area (10³m²)</u>	<u>Building Area Per Stage (m²)</u>	<u>Year of Completion</u>
Oak Ridge	K-25	(3024) ^a	162	54	1945
	K-27	(540) ^a	35	64	1946
	K-29	300	27	90	1951
	K-31	600	69	115	1951
	K-33	640	131	205	1954
	Subtotal ^a	1618	424		
Paducah	C-310	60	.5	87	1953
	C-331	400	47	117	1953
	C-333	400	47	117	1954
	C-335	480	100	208	1953
	C-337	472	100	208	1954
	Subtotal	1812	299		
Portsmouth	X-326	2340	110	47	1956
	X-330	1100	130	118	1955
	X-333	640	133	208	1955
	Subtotal	4080	373		

^a The original facilities in K-25 and K-27 have been shut down. Building K-25 now houses 78 stages.

TABLE 6-2
WASTE DISPOSAL AT GASEOUS DIFFUSION ENRICHMENT FACILITIES
Source: NRC79

<u>Facility</u>	<u>Number of Waste Disposal Areas</u>	<u>Burial Sites</u>		<u>Waste Lagoons</u>	
		<u>Volume (10³m³)</u>	<u>Activity (Ci)</u>	<u>Volume (10³m³)</u>	<u>Activity (Ci)</u>
Oak Ridge	3	140	14	---	---
Paducah	14	7	1200	4 ^a	250
Portsmouth	4	1	6	400 ^b (several other smaller ones)	---

a DOE79b reports there are 14 waste areas and a waste lagoon; NRC79 only reports 13 areas and does not mention the lagoon. The difference between the waste estimates of DOE79b and NRC79 are assumed to be the wastes in the lagoon.

b Estimated from a figure in ERDA77a. Assumed 2 m depth of material.

uranium that was recovered from fuel reprocessing and thus contained low levels of fission products. Also, the Paducah plant processes tails from the other plants and thus may end up with more waste.

The large volume of material for the waste lagoon at the Portsmouth site may be due to sludge from water purification and may not contain process related radioactivity. The supply water has a high solids content and results in the production of about 14,000 m³ per year of sludge. About 420,000 m³ of this sludge would be accumulated over a 30 year period (present life of plant). The sludge contains 3% silicon, 3% chromium, and 20% calcium plus magnesium.

There are several sources of waste mentioned for the Portsmouth plant which may not be included in Table 6-2 (ERDA77). These are:

- Wastes from changing the alumina air cleaning traps; 205 kg per trap, times 5 changes per year (after uranium removal, the trap contains about 2% uranium by weight) results in 1000 kg per year or 30,000 kg in 30 years. Assuming a density of 2 g/cm³, this gives 15 m³.
- About 62 m³ of scrap are buried in the X-749 burial site each year.
- Four plots with a total area of 14,000 m² are used for disposal of contaminated oil and sewage sludge. The material is plowed in to a depth of about 20 cm.
- About 400 kg of uranium per year from cleaning UF₆ cylinders is discharged to pond X-701B (900 m²). About 140 m³ of sediment is removed each year and placed near the pond. The volume after 30 years would be 5,200 m³.
- If reprocessed irradiated fuel is used, about 10 Ci/year of Tc-99 may be discharged to ponds.

Two approaches are used to estimate the existing contamination in the process equipment of gaseous diffusion enrichment plants. One approach

uses estimates of surface contamination from E180 and E181 and general estimates of the surface area of process equipment. The second approach scales results from the reference uranium fuel fabrication facility in Section 7.1. The techniques are:

- Estimate the contaminated surface area associated with a diffusion stage and assume an initial concentration of 10 g uranium per square meter of area. It is also assumed this level of concentration can be reduced to an average of 2 g/m² with initial decontamination.
- Assume there is a relationship between the volume of process equipment and quantity of contamination and the building area occupied by process equipment. Based on this relationship for the reference uranium fuel fabrication facility (e.g., kilograms of contamination and cubic meters of waste per square meter of facility) and the process area for the enrichment plant, calculate the existing contamination and waste volume.

Both techniques entail considerable uncertainties. The first technique uses general contamination levels based on E180 and E181, and estimates of the surface area of process equipment. Based on information in VI79, it is estimated that each diffusion stage and the associated equipment contains about 900 m² of contaminated surface area. Most of this area is due to an estimated 900 barrier tubes (based on the spacing of tubes in the end plate of the diffuser), 2.75 m in length (each tube has an area of about 0.9 m²--total of inside and outside) and about 100 m² is due to the diffuser vessel (5.8 m by 3.4 m in diameter). Other equipment, such as the compressors and piping contributes several square meters, a small fraction of the total.

The second technique is based on scaling contamination linearly with process space. This assumes the amount of contaminated equipment per unit

area of process space, or, if desired floor space, is relatively constant for different facilities. This entails many uncertainties, including differences in heights of equipment bays and equipment, and inherently assumes basic similarities in the respective facility processes. The factor for the reference uranium fuel fabrication plant is 0.014 kg of uranium per square meter of process area (140 kg uranium divided by 10,000 m² of process area). The process area for the main building of the reference fuel fabrication plant (Table 7-2) was divided by two because the facilities were built to provide sufficient space to double the output of the reference plant.

In order to compare the uranium inventory estimates from the two techniques, the average number of stages and average building space of the GDE plants are used. Based on the approximations of the techniques individual estimates are not warranted.

Estimates for the uranium inventory in the GDE plants after initial plant cleanout and equipment flushing are:

Stage Technique: 1.8 kg of U per stage times 2500 stages
(average of three plants) equals 4500 kg of uranium.

Process Area Technique: 0.014 kg of U per m² times 3.7×10^5 m²
of process area (average of three plants) equals 5200 kg of uranium.

Given the uncertainty of the techniques, the closeness of the results may be fortuitous. In any case, there is good agreement, and the results are combined to give an estimate of 5000 kg of uranium for each of the facilities. Given the minimal information available, it is not justified to try to distinguish the difference between the facilities.

The above contamination estimates are based on a concept of final inventory cleanout (part of operations, not D&D) after shutdown and flushing the process equipment with a liquid (preferably acid) wash. It is estimated that the quantity of uranium after final inventory cleanout, but prior to flushing the system would be twice the above estimate (E180, E181), or 10,000 kg. The liquids and solids from inventory cleanout and initial decontamination are processed in the plant systems. The uranium is recovered and the wastes are condensed into a minimal volume (this follows the assumptions of E180, E181).

Based on the information in Table 6-2 and the supplemental information for the Portsmouth plant (ERDA77) there are several tens of thousands of cubic meters of buried waste or lagoon sediments and sludges at the sites. The referenced information indicates somewhat smaller volumes at the Paducah site, but this could be due to incomplete information. The supplemental information for Portsmouth indicates these wastes contain thousands of kilograms of uranium. Uranium is the dominant radionuclide except for Tc-99 from processing uranium from fuel reprocessing plants. If a significant amount of reprocessed uranium is used as feed material, it is estimated that 10 to 60 Ci/year of Tc-99 will be included in the solid wastes (ERDA76 and ERDA77). Technetium-99 is a long-lived (half life of 2.1×10^5 years) fission product that has a lower discrimination factor in reprocessing than the other fission products.

6.1.3 D&D Alternatives and Wastes

The D&D alternatives and techniques for GDE plants will be similar to those for fuel fabrication plants (Section 7.1 and 7.2).

The D&D wastes are scaled from uranium fuel fabrication plants using the process area scaling technique described in the previous section. The scaling factors for LLW and unrestricted waste are $0.08 \text{ m}^3/\text{m}^2$, and $0.5 \text{ m}^3/\text{m}^2$, respectively. These are based on values from the uranium fuel fabrication facility of 800 m^3 , $5,300 \text{ m}^3$, and $10,000 \text{ m}^2$ for LLW, unrestricted waste, and process area, respectively (Tables 7-2 and 7-3). The value for the process area (Table 7-2) is based on one-half of the main building, since it was designed with sufficient space to allow doubling the process capacity. Using these factors and the inventory estimate from Section 6.1.2, the estimated D&D wastes for a single gaseous diffusion enrichment plant are:

Uranium Inventory:	5000 kg
Low-Level Waste:	$30,000 \text{ m}^3$
Unrestricted Waste:	$190,000 \text{ m}^3$

Because of the classified nature of the facilities, it is possible that all of the materials will be handled as a form of restricted waste.

Given the coarseness of the estimates, it is not appropriate to scale them to the specific features of each of the facilities. However, the wastes from the Portsmouth facility may be higher than those for the Paducah facility, based on the larger process area and greater number of enrichment stages (Table 6-1). If there has not been any cleanup of the deactivated areas of the Oak Ridge facility, the D&D wastes there would also be expected to be higher than those for Paducah.

The buried wastes and waste lagoons discussed in Section 6.1.2 are not included in the D&D wastes. Depending on the volumes and activities of the

wastes, these areas may be dedicated as LLW sites.

The primary contaminant in the process equipment, facilities and lagoons will be uranium. The enrichment will range from depleted uranium (about 0.2 to 0.3%) to highly enriched uranium. Depending on whether reprocessed irradiated fuel is used as feed, low levels of transuranics and Tc-99 may also be present. The chemical form of the uranium will probably be as hydrolyzed UF_6 or a fluoride compound.

The D&D wastes will include tanks, diffuser containers (up to 20 m³ in volume), motors, compressors, and building rubble. Given the highly classified nature of the facilities and the corrosive nature of UF_6 , it is doubtful whether any material will be recycled. However, the wastes will include large volumes of steel, nickel, and aluminum, which would have a high recycling value if they were adequately decontaminated.

7. FUEL FABRICATION FACILITIES

Fabrication plants convert fissile material from the oxide or hexafluoride form to reactor fuel assemblies. There are fabrication plants for low-enriched light water reactor (LWR) fuel, for high-enriched Naval and other reactor fuels, for mixed oxide (uranium and plutonium) fuel, and for fuel containing thorium. There are about 13 uranium fuel fabrication facilities operating in the U.S. At least six mixed oxide (uranium and plutonium) plants have been operated, but these are all essentially deactivated or in standby status at this time. Most of the mixed oxide (MOX) plants are located at sites where there are uranium fuel fabrication plants. This, plus the changing status of facilities, makes it difficult to give accurate counts of the number of facilities. This chapter identifies the operating and shutdown facilities, and uses reference facilities to characterize the actual facilities and wastes from their D&D. The primary emphasis is placed on facilities for fabricating fuel for light water reactors.

Uranium and MOX facilities are treated in the same chapter because of the similarity of many of the processes; however, the presence of plutonium in the MOX facilities makes the nature of the radiological contamination considerably different.

Table 7-1 provides a list of the uranium fuel fabrication plants and their operating status. The MOX plants and facilities for highly enriched uranium are also listed in Table 7-1. The MOX plants are identified by the indication of a license for plutonium. Jenkins et al, (Je79) also list MOX plants operated by Westinghouse at Anderson, South Carolina (was proposed, but was not built); Getty Skelly Oil at Erwin, Tennessee (probably

TABLE 7-1. URANIUM AND MIXED OXIDE LWR FUEL FABRICATION PLANTS

SNM ^a License	Licensee	Plant Location	Plant Feed Material	Plant Product	Type Facility Amount of SNM ^b		Status of Facility	
					kg U-235	kg Pu	Uranium	Plutonium
1168	Babcock and Wilcox ^c	Lynchburg, VA	UO ₂ Pellets	Fuel Assemblies	20,000	-	Operating	
145	Babcock and Wilcox ^d	Apollo, PA	UF ₆	UO ₂ Powder or Pellets	14,350	-	Operating	
414	Babcock and Wilcox ^c	Leechburg, PA	--	Fuel Assemblies	225,000	1,000	Operating	Inactive
1067	Combustion Engi- neering	Windsor, CT	UO ₂ Powder		17,500	-	Operating	
33	Combustion Engi- neering	Hematite, MO	UF ₆	UO ₂ Powder or Pellets	4,100	-	Operating	
1227	Exxon Nuclear Co. ^f	Richland, WA	UF ₆	Fuel Assemblies	10,000	10	Operating	Inactive
696	General Atomic ^f	San Diego, CA			990	4	Operating	Inactive
1097	General Electric ^f	San Jose, CA			-	-	Deactivated	
960	General Electric ^f	Wilmington, NC	UF ₆	Fuel Assemblies	50,000	-	Operating	--
	General Electric ^f	Pleasanton, CA	UF ₆	Fuel Assemblies RD	1,000	150	Standby	Inactive
1174	Kerr-McGee	Crescent, OK	UF ₆		-	11	Standby	Standby
124	Nuclear Fuel Services	Erwin, TN	UF ₆ Pellets	UO ₂ Powder or Pellets	4,300	-	Operating	--
21	Rockwell Inter- national	Canoga Park, CA			1,500	3.5	Operating	Inactive
23	Texas Instruments	Attleboro, MA		--	350	-	Operating	--
368	United Nuclear	Montville, CT		--	12,000	-	Operating	--
777	United Nuclear	Wood River, RI		--	850	-	Operating	--
	United Nuclear	New Haven, CT	UO ₂ Pellets	Fuel Assemblies			Shutdown	
1107	Westinghouse	Columbia, SC	UF ₆	Fuel Assemblies	50,000		Operating	--
1120	Westinghouse	Cheswick, PA		Fuel Fabrication	10	4.5	Terminated February 1980 (Being Decontaminated)	

^a Special nuclear materials license numbers.

^b The licensed amount of SNM, uranium-235 or plutonium, for the indicated SNM license, is shown. The mixed oxide facilities are those with a licensed amount of plutonium. The amount of licensed material is a rough indication of the relative size of the facility. Information from NRC81a.

^c Babcock & Wilcox also has a high enrichment license for 30,000 kg of U-235 and a license for a Research and Development Laboratory for irradiated fuels (6 x 10⁶ Ci and 900 kg of U-235 at Lynchburg); these are licenses SNM 42 and 778, respectively (NRC81a). The facility is also licensed for highly enriched uranium.

^d Effective October 1976, Babcock & Wilcox combined accounting for the high enriched uranium inventory at the Apollo and Leechburg, PA, facilities (licenses 145 and 414). The high enriched plant at Apollo, which is being decommissioned (NRC81a), was formerly owned by Nuclear Materials and Equipment Corp. (EN80).

^e Formerly owned by Gulf United Nuclear.

^f Personal communication, R. Thomas, U.S. Nuclear Regulatory Commission, Walnut Creek, CA, May 1, 1982.

Nuclear fuel services); Combustion Engineering at Windsor, Connecticut; and Babcock and Wilcox at Lynchburg, Virginia. These have not been listed in Table 7-1 because NRC81a does not indicate a plutonium license. If there are plants at these locations, they are probably all inactive, since most of the plutonium plants are presently inactive.*

There are several activities at a number of the plants. While the existence of several different operations at a plant increases the chances of replacing discontinued operations with different processes (e.g., installation of a new activity may not require complete D&D of the former facility), the existence of numerous activities may also make D&D more difficult.

The list of facilities and associated information in Table 7-1 is based on a composite of information from E180, Je79, EPA79, and NRC81a, and on some updating from private communications.*

Uranium fuel fabrication plants receive feed material as uranium hexafluoride or uranium dioxide. The feed material for power reactors is enriched to about 2 to 4% U-235 (E180). The specific activity of enriched uranium is much higher than for natural uranium, since the half lives of U-234 and U-235 are shorter than the half life of U-238. Although the intent of enrichment is to increase the abundance of U-235, the abundance of U-234 is also increased.

If the uranium feed is received as uranium hexafluoride, it is converted to UO₂ either by an intermediate conversion step to ammonium

* Personal communication, R. Thomas, U.S. Nuclear Regulatory Commission, Walnut Creek, CA, May 1, 1982.

diuranate or by a direct process where UF_6 is hydrolyzed and reduced to UO_2 . The uranium is pelletized and sintered and placed in fuel rods.

7.1 REFERENCE URANIUM FUEL FABRICATION FACILITY

Reference fuel fabrication facilities for LWR fuel are described in EPA73, EPA79, NRC81, and E180. The reference facility from E180 is adopted for this evaluation, since more details, especially for D&D, are given for it than for the other studies. This reference facility is based on the General Electric Wilmington, NC, plant. Although, the Wilmington facility is larger than many of the operating plants, it is representative of contemporary facilities (E180). The lifetime of the facility is expected to be 30 to 40 years. Several plants that have operated for shorter periods have been terminated because of market conditions.

7.1.1 Facility Description

The reference facility uses two head-end processes for converting gaseous UF_6 to UO_2 . The primary method used is a chemical process involving hydrolysis of vaporized UF_6 to ammonium diuranate (ADU), precipitation of ADU, and reduction and calcining of the ADU to dry UO_2 powder. The secondary method involves direct conversion of UF_6 vapor to U_3O_8 in a flame conversion reactor and reduction of U_3O_8 to UO_2 powder in a reduction calciner. The associated facility components for both processes are analyzed in this evaluation. A reference site and associated climatology, population, etc., are developed by E180. These have minimal impact on the D&D and are not presented here. The estimated amount of deposited

material from airborne effluents is within normal background variations (i.e., less than 0.5 pCi/g for the uranium nuclides, assuming mixing within the top 1 cm of soil).

The plant capacity is 1000 MT of uranium per year. Parameters for the plant are summarized in Table 7-2. The buildings are generally built with 10 to 15 cm thick concrete floors. The lower meter of the outside walls is concrete, with the remainder of the outer structure being steel frame and metal siding. The inner walls are concrete block which is painted or covered with sheetrock. The process areas have sealed concrete floors or tiled floors.

A simplified flow diagram of the facility is given in Figure 7-1. A gadolinia shim-rod loop similar to the pellet-formation fuel-rod loop and the scrap recycle loop have been deleted to simplify the diagram.

Production activities fall into three basic categories:

- Chemical conversion of UF_6 to UO_2 ;
- Mechanical processing, including pellet production, fuel rod fabrication, and fuel bundle assembly; and
- Recovery of uranium from scrap, off-specification material, and chemical wastes.

Uranium hexafluoride is received at the site in pressure cylinders. The feed which is enriched from 2 to 4 percent by weight in U-235, arrives in 2300-kg, 76 cm diameter cylinders. The cylinders are protected in transit by an outer shipping container. Uranium enriched slightly above 4 percent is received in 25 kg, 12.7 cm diameter cylinders that are also packed in protective shipping containers. The cylinders are weighed for accountability purposes, upon receipt, and then either stored or

TABLE 7-2

PARAMETERS FOR REFERENCE URANIUM FUEL FABRICATION FACILITY
Source: E180

<u>Characteristic</u>	<u>Parameter</u>
Uranium Processing Capacity (MT)	
Daily Capacity (Uranium)	3.3
Daily Capacity (UO ₂)	3.8
Yearly Production	1,000
Operating Lifetime (years)	40
Plant Efficiency (percent)	
Production Efficiency	80
Recycle of Uranium Scrap	20
Product Composition (Percent)	
UO ₂ Pellets	99
UO ₂ Powder	1
Site, Fenced Restricted Area (ha)	3
Buildings (m ²)	
Main Manufacturing Building*	
Ground Area	17,000
Floor Space	19,300
Chemical Metallurgical Lab	770
Waste Recycle Control Room	340
UO ₂ Powder Warehouse	810
Ventilation and Air Cleaning	
Number of stacks (must have 1 or 2 HEPA filters)	32
Waste Lagoons (lined) (m ²)	
Nitrate (2)	5,200
Fluoride	
Settling	5,600
Aeration Lagoon	110

* Large enough to allow doubling production.

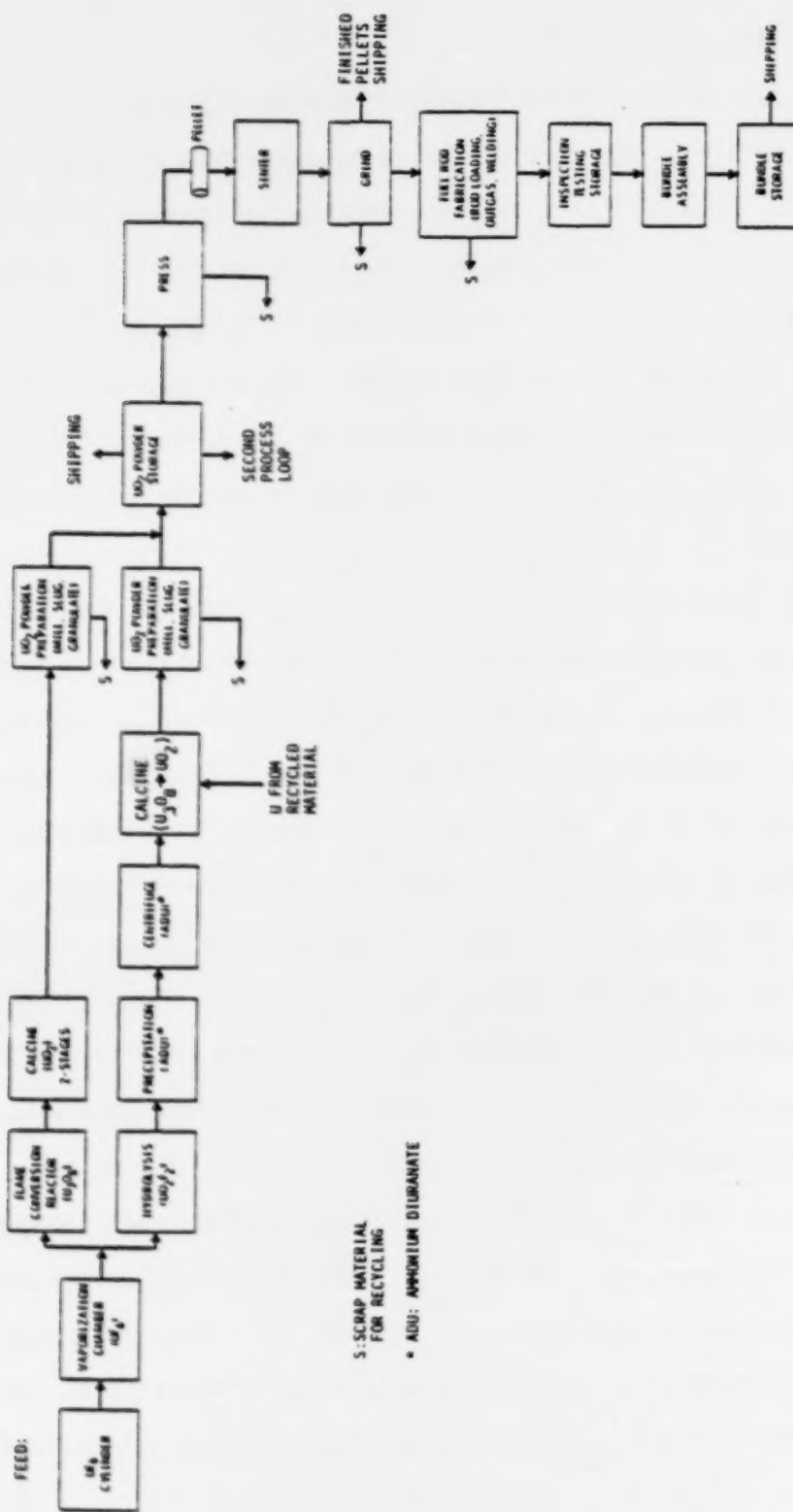


FIGURE 7-1. SIMPLIFIED PROCESS DIAGRAM OF FUEL FABRICATION PLANT

SOURCE: E180

transferred to the process area.

For the chemical conversion process (the primary process), the cylinders are transferred to the vaporization room, where they are placed (using a bridge crane) in one of 11 different vaporization chambers. The cylinders are heated by electrically heated air to volatilize the stored UF_6 , which is piped to a vessel filled with water. The UF_6 gas reacts with water and is hydrolyzed to form UO_2F_2 and HF . The off gas is scrubbed to recover HF as a byproduct. The UO_2F_2 solution is circulated through one of two identical hydrolysis storage tanks until the proper UO_2F_2 concentration is reached (E180).

The UO_2F_2 solution is then transferred to the chemical precipitation tank, where ammonium hydroxide is added to the UO_2F_2 solution to precipitate uranium as ammonium diuranate (ADU). The resulting ADU solution is transferred to a digester tank to aid the precipitation process. Water is removed from the resulting ADU slurry by centrifuging. The precipitate is continuously fed to the horizontal chamber of a gas-fired reduction calciner, where the ADU is defluorinated, reduced, and dried to produce ceramic-grade uranium dioxide powder. The UO_2 powder is placed in 19 liter cans for transport to the second-floor UO_2 powder preparation area (E180).

In the direct conversion process (the secondary feed process), four flame conversion reactors are used to directly convert UF_6 to U_3O_8 . The four reactors are connected to three vaporization chambers that are capable of heating and stripping UF_6 from the UF_6 cylinders in a cycle that permits continuous operation of the reactors. Natural gas, UF_6 , and oxygen are mixed in the reactors at a carefully controlled temperature to convert UF_6 to U_3O_8 and HF . The HF contained in the reactor gases is scrubbed and

collected in one of two identical powder collection pots. The U_3O_8 is then pneumatically transferred to a hopper, collected in 19 liter cans, and weighed before further processing. The U_3O_8 is further treated by crushing and granulating it to a powder suitable for further processing as necessary. The U_3O_8 powder is then fed to a horizontal, gas-fired reduction calciner, where it is defluorinated, reduced and dried to produce ceramic grade UO_2 powder. The calciner discharges the UO_2 powder through an air-lock system into cans. The UO_2 powder is then transported to the second floor UO_2 powder preparation area for treatment to enhance its pellet-forming properties.

Pellet Formation and Fuel Rod Assembly - Uranium dioxide pellets are formed in a two-step process: densifying and pelletizing. The uranium dioxide is pulverized, compacted, and granulated to increase its density and size distribution to that desired for pellet formation. To accomplish this, the UO_2 is processed through a size-reduction hammer mill, a predensifier press, and a granulator that crushes the compacts from the press into material of a uniform particle size. The sized UO_2 particles are placed in buckets, sealed, and transferred to the mezzanine storage area. The densified material is analyzed for uranium and moisture content.

In the second step, the densified UO_2 powder is pelletized, and the pellets are sintered, ground to finished dimensions, and loaded into fuel rods. The densified UO_2 powder is loaded in hoppers that feed the pellet presses. The pellets are sintered in a reducing atmosphere (hydrogen) in one of five electrically heated furnaces (sintered to about 95% of theoretical UO_2 density) and ground to correct size by centerless grinders equipped with diamond-grit work wheels. The finished pellets are placed in

trays and stored until needed.

The pellets are pushed into zircaloy fuel tubes which have been welded closed at one end. Loaded tubes (now fuel rods) are placed in trays and transferred to one of three rod-outgas ovens to remove all traces of moisture. The individual rods are then inserted into a controlled atmosphere weld box. After air is evacuated, the rod is filled with helium and the end plug automatically inserted and welded into position. The rods are placed in trays and stored in cabinets for eventual assembly into fuel bundles.

Fuel Bundle Assembly and Final Inspection - Each fuel rod is scanned for U-235 content, using a neutron source and gamma radiation detectors, to confirm the enrichment. Rods with the desired enrichment of uranium are then placed on assembly tables for assembly into fuel bundles. The rods are visually inspected for cleanliness and damage and replaced as necessary.

After assembly, bundles are leak-tested in a vacuum chamber. Helium leaking from fuel rods is detected in the exhaust air, using a helium mass spectrograph.

There is also a smaller process loop for producing $\text{UO}_2/\text{Gd}_2\text{O}_3$ shim rods. Gadolinia is a neutron poison, and the shim rods are used to obtain the desired power profile in a reactor. The process, other than including blending of UO_2 and Gd_2O_3 , is similar to the fuel rod loop.

Scrap Recovery - Uranium scrap in various physical and chemical forms is generated at numerous points in the process. The material is reprocessed through scrap recovery equipment which produces $\text{UO}_4 \cdot 2\text{H}_2\text{O}$. This material is recycled to the calciner, where it is injected into the process

stream.

Scrap uranium to be reprocessed (21-kg lots) is slowly injected through a discharge chute into one of nine dissolver tanks filled with hot nitric acid (88°C). After dissolution, the uranyl nitrate is filtered, cooled, and routed to one of three precipitation tanks. Ammonium hydroxide and hydrogen peroxide are used to precipitate uranium tetroxide from the solution. Water is removed from the UO_4 slurry in a centrifuge, and the precipitate is pumped to a gas-fired reduction calciner, where it is converted to UO_2 (E180).

Uranium scrap mixed with foreign materials (gadolinium slugs and press residue, gadolinia grinder sludge, rejected gadolinium pellets, nitrate wastes, combusted wastes, solid wastes, radwastes, etc.) not meeting quality standards for processing is shipped to an off-site contractor for rework and recovery of uranium. The recovered uranium is returned to the facility and processed through the scrap processing system (E180).

Liquid Waste - Liquid waste streams from the different chemical processes are kept separate to facilitate uranium recovery operations. They are classified as nitrate wastes, fluoride wastes, and radwastes. Each stream has its own quarantine tank system within the main building to permit temporary storage of the waste liquid. Based on uranium content, the liquid wastes are either released for final waste treatment or are recycled to recover the uranium residuals (E180).

Nitrate wastes generated during scrap recovery operations are treated on a batch basis. Nitrate wastes are treated with lime to precipitate and settle out any uranium compounds. The clarified liquid is discharged to the nitrate storage lagoons (lined evaporation ponds). Clarified nitrate

solution from the nitrate lagoons is pumped back into the waste treatment facility for further concentration before shipment to a paper manufacturing firm. The paper manufacturing firm dilutes the nitrate solution (approximately 3000 to 1) by mixing it with their liquid wastes to enhance the biodegradation processes within their waste treatment facility.

The uranium-bearing sludge collected in the bottom of the precipitation tank is centrifuged to remove the residual liquid and placed in 19-liter buckets. If the uranium content of the sludge warrants, the waste is shipped to an off-site contractor for reprocessing. The residual liquid from the centrifuge is recycled back into the precipitation tank.

If they meet process limits, chemical wastes generated from the UF_6 to UO_2 conversion process are pumped from the fluoride waste collecting and quarantine tank system to a 246 m^3 storage tank. If the fluoride wastes do not meet process limits, they are recycled back into the process for rework through the recycle system. Liquid fluoride waste in the 246 m^3 storage tank is continuously recirculated to keep solids suspended until the liquid is pumped to a 379 m^3 settling tank. The solid material in this tank is centrifuged out and stored in 19-liter pails until it is recycled or discarded. The supernate from this tank is decanted on a batch basis into two 45 m^3 treatment tanks. In these tanks, the waste liquid is treated with lime slurry ($Ca(OH)_2$) to precipitate and entrap uranium residuals in a calcium fluoride matrix. The liquid waste is pumped into the top of a packed stripping column. In the column, steam is intimately contacted with the liquid waste to strip ammonia from the waste solution. The stripped fluoride solution emerging from the bottom of the column is pumped to the fluoride storage lagoons where the CaF_2 solids are allowed to settle. The

clarified liquid in the storage lagoons is pumped to aeration lagoons. Finally, the fluoride waste solution is sent to the chemical lagoon, where it is mixed with other chemical waste liquids from the plant and released to a drainage ditch that flows off site to the river.

Calcium fluoride solids on the bottom of the fluoride storage lagoons are periodically removed and stored on site for eventual reprocessing to recover the uranium residuals. Plants using the ADU process store the resulting CaF_2 on site for eventual disposal.

Solid Waste Processing - Solid wastes such as paper, rags, mops, plastic, wood, protective clothing, damaged tools, and equipment are constantly generated during plant operations. These waste materials are collected at the point of origin in designated containers and transferred to the waste handling facility in the fuel manufacturing building. In the waste handling facility, uranium-bearing materials are segregated into non-combustible and combustible categories. Combustible materials are incinerated, the uranium is recovered, and the residual is disposed of at a licensed low-level waste site. Noncombustible materials are segregated into materials from which uranium can be recovered and wastes which are sent to a LLW site.

7.1.2 Existing Contamination

At shutdown and before final inventory cleanout, the uranium inventory in the reference plant is estimated to be about 790 kg of uranium; after final inventory cleanout, it is estimated to be approximately 270 kg. About 120 kg of this uranium is in the ventilation system, with the remaining 150 kg in the process equipment. Final cleanout, done

periodically during plant operations between processing campaigns, removes process materials, chemicals, trash, visible quantities of contamination, scrap, scrap solutions, and contaminated solutions from the facility. Empty product, scrap, and waste handling tanks are also rinsed to flush out the remaining process solutions. These operational inventory cleanout operations are considered to be part of the normal plant operations. The wastes from the cleanout operation are processed through the scrap and waste systems, and the uranium is recovered (E180).

Decommissioning decontamination operations start with a thorough flushing and chemical decontamination of all process equipment and piping. Decontamination procedures include spray cleaning, hot corrosive acid flushing, and dry wiping.

A list of the process and facility equipment, the distribution of uranium after the initial D&D decontamination, and the volumes of unrestricted waste and reusable materials are given in Appendix B. A summary of this information is given in Table 7-3.

The uranium inventory when the facility is shut down is estimated to be 790 kg. This is reduced to 270 kg by the final inventory clearout. This is further reduced to 140 kg by the initial decontamination associated with D&D. The disassembly and decontamination of equipment and facilities associated with the D&D effort reduces the inventory to about 100 kg. The uranium, waste solutions, and combustible cleaning materials from the D&D operation are processed through the facility scrap recovery plant, incineration, and radioactive waste systems. Uranium which has been concentrated in waste solutions is sent off site for recovery by other plants. Therefore, decontamination activities only contribute a minimal

TABLE 7-3

SUMMARY OF D&D WASTES FROM PROCESS EQUIPMENT

REFERENCE FUEL FABRICATION FACILITY

Source: E180

Location/Process	Inventory After Initial Decon (kg of U)	Volume of Wastes		
		Scrap or Surplused (m ³)	Unrestricted Waste (m ³)	Restricted LLW (m ³)
UF ₆ Vaporization Area	3.5	37	2	180
Chemical Area	70	70	510	200
Powder Storage	1.6	26	16	9
Pelletizing Room	42	7	120	23
Pellet Sintering	0.8	95	140	59
Pellet Grinding	4.4	94	36	5.3
Rodding Room	0.75	230	60	-
Gadolinia Rod Fabrication	4.7	45	31	18
Uranium Scrap Recovery	1.4	2	3	27
Support Labs and Shops	3.6	250	170	41
Radwaste Processing	0.8	-	160	-
Laundry	-	2	5	21
Change Rooms	-	7	-	-
Incinerator	8	7	12	26
HEPA Filter Room	0.3	-	-	-
Fluoride Waste Treatment	0.8	700	1,000	100
Nitrate Waste Treatment	0.35	420	40	10
Radwaste Effluent Treatment	-	-	57	40
Powder Warehouse	-	180	30	-
Uranium Storage Pads	-	-	-	-
UF ₆ Cylinder Storage	-	150	20	-
Waste Treatment Building	-	-	65	10
Other (Misc. Material)	-	-	500	35
TOTAL	140	2,300	3,000	800

amount of waste to the D&D wastes from actual materials in the facility.

In addition to the activity listed in Table 7-3, about 38,000 MT (30,000 m³) of sediments from the CaF₂ waste ponds are accumulated during the life of the plant. This material, composed primarily of CaF₂, contains about 0.2% uranium (by weight) and recoverable hydrofluoric acid. The CaF₂ is precipitated in the fluoride waste lagoons and is periodically removed from the lagoons and stockpiled on the site (on plastic pads) during plant operations. The uranium content equals or exceeds most uranium ores mined today. Therefore, it is assumed that the value of the enriched uranium will equal or exceed the costs of recovery, and the material will be shipped off site for processing (E180).

7.1.3 D&D Alternatives and Wastes

The D&D alternatives are similar to those for other uranium facilities. The use of SAFSTOR will only delay the need to eventually DECON the facility. Therefore, the primary usefulness of SAFSTOR is to provide a standby operation to allow for future reuse of the facility. Given the eventual need for DECON, the waste estimates are based on DECON.

7.1.3.1 Volume and Activity of Materials

Estimates of the volume and activity of wastes are given in Table 7-3. The activity estimates are for after the initial decontamination, but prior to the final decontamination associated with disassembly of the equipment. The final disassembly is estimated to remove an additional 30% of the contamination, resulting in a net value of 100 kg of uranium. However, this 30% is an average ranging from complete removal from some equipment to

no removal from other equipment.

Almost 40% of the volume of material from D&D of a fabrication plant is recyclable scrap or equipment that can be excessed for unrestricted use. The 6100 m³ of material is composed of 800 m³ LLW, 3000 m³ unrestricted waste and 2300 m³ recyclable material. Table 7-3 gives a breakdown of this material by facility process. Tables in Appendix B provide a more detailed breakdown by specific items of equipment.

The sediment from the fluoride lagoons (CaF₂ and uranium) is not included in the previous estimates of wastes. The sediment is periodically cleaned from the pond and stockpiled on a pad. The volume at the end of facility operations is estimated to be 30,000 m³, containing about 76 MT of uranium (0.2%). It should be cost effective to ship this material to an off-site reprocessor, but the presence of the material should be recognized. Since it may be considered a by-product, it is not specifically designated a D&D waste.

7.1.3.2 Chemical and Physical Form

The radioactive contamination is due almost solely to uranium. For facilities producing fuel for light water power reactors, the uranium will generally be enriched in U-235 from 2 to 4%. Enriching uranium in U-235 also results in a proportional or greater increase in the relative amount of U-234. The specific activity of the uranium is proportional to the degree of enrichment. Natural uranium has a specific activity of 334 nCi/g, 331 nCi/g, and 15.4 nCi/g for U-238, U-234, and U-235, respectively. If uranium is enriched from 0.72% U-235 to 4% U-235, the activity of U-234 will increase by more than a factor of 5 to over 1,800 nCi/g, and

the activity of U-235 will increase to 85 nCi/g. These changes in specific activity also increase the gamma exposure rate.

The chemical form of uranium in the fabrication plant ranges from UF_6 and ammonium diuranate to U_3O_8 and UO_2 powder and pellets and covers the full range of solubilities. The chemical form of contamination can be related to the location within the basic process as summarized in Table 7-3 and given in more detail in Table B-1. The solubility of the various compounds of uranium is discussed in Section 4.1.1.1.

7.1.3.3 Materials

The basic materials in the D&D waste and recyclable materials are identified in Tables B-1 and B-2. Steel from decontaminated tanks (see Table B-2) represents a large amount of the recyclable scrap.

7.1.3.4 Residual Materials

The residual materials are identified in Table B-2. About 2300 m^3 of the 5300 m^3 of potential unrestricted waste may be recycled if there is an adequate market for scrap and the specific equipment.

The 30,000 m^3 of fluoride wastes can also be included as a residual, recyclable material for recovery of uranium.

The basic physical plant facilities are left in place.

7.2 URANIUM FUEL FABRICATION FACILITIES

There are two basic types of uranium fabrication facilities--high-enriched uranium and low-enriched uranium (less than 4 to 5%) (NRC81).

Within these two types, there are facilities for fuel production and research and development facilities. There is also a wide spectrum of production facilities. Some facilities conduct the total fabrication process from UF_6 to fuel assemblies. Others either only produce UO_2 pellets from UF_6 or fabricate fuel rods and assemblies from UO_2 pellets.

7.2.1 Description of Uranium Fuel Fabrication Facilities

The production facilities for LWR fuel are listed in Table 7-4. This list is extracted from Table 7-1, which listed LWR facilities and facilities for fabricating Navy ship fuels, research and test reactor fuels, and mixed oxide fuel, as well as research and development. Primary emphasis is given to the LWR facilities. The referenced reports do not designate the Babcock and Wilcox (B&W), Leechburg, PA, facility as a LWR fuel facility (E180, W181); however, since its license is for low-enriched uranium, it is included in this category. The Leechburg plant also has a license for high-enriched material. Elder and Bladnik (E180) indicate the General Electric Plant at Pleasanton, CA, the Kerr-McGee plant at Crescent, OK, and the United Nuclear plant at New Haven, CT, are used for LWR fuel. However, since NRC81a does not show active low-enrichment licenses for these plants, they are not listed in Table 7-4.

The B&W Lynchburg and Apollo plants and the Combustion Engineering (CE) Hematite and Windsor plants function together, in that one produces UO_2 pellets and the other fabricates fuel rods from the UO_2 pellets. Therefore, in order to estimate D&D wastes, these dual facilities will be combined. If there is a desire to obtain separate estimates, the pertinent information can be obtained from Table 7-3 and Appendix B. As a rough

TABLE 7-4
CURRENT LWR FUEL FABRICATION PLANTS
Source: W181

Facility	Plant Feed Material	Plant Product	Plant Capacity (MTU/year)	
			Current	1985 ^a
Babcock & Wilcox Lynchburg, VA	UO ₂ pellets ^c UF ₆	Fuel Assemblies	230	830 ^b
Babcock & Wilcox Apollo, PA	UF ₆ ^c	UO ₂ Powder and Pellets		^c
Babcock & Wilcox Leechburg, PA		--		
Combustion Engineering Hematite, MO	UF ₆ ^d	UO ₂ powder or pellets		^d
Combustion Engineering Windsor, CT	UO ₂ powder ^d	Fuel Assemblies	150	150
Exxon Nuclear Richland, WA	UF ₆	Fuel Assemblies	665	1,030 ^e
General Electric Wilmington, NC	UF ₆	Fuel Assemblies	1,500	1,500
Westinghouse Electric Columbia, SC	UF ₆	Fuel Assemblies	750	1,600

^a Estimated.

^b Babcock and Wilcox plans to expand operations to increase capacity to 1,200 MTU/year by the early 1990's. The capacity listed in the table for 1985 is an interpolation of present and future capacity. In addition, a UF₆ to UO₂ conversion and UO₂ pelletizing operations will be added.

^c Currently, the B&W Apollo plant converts UF₆ to UO₂ powder and ships the UO₂ to its Lynchburg plant for fabrication into fuel assemblies.

^d The Combustion Engineering (CE) Hematite plant produces UO₂ pellets or powder which are then transferred to the CE Windsor plant for fabrication into fuel assemblies.

^e Expanded to 1,030 MTU/year in 1980.

approximation, over 80% of the residual uranium and 50% of the LLW are due to the UF_6 to UO_2 -pellet conversion part of the process. The necessity of duplicating some facilities (e.g., scrap reprocessing and waste treatment) will make the wastes from split facilities somewhat higher than from a single facility.

Wild et al. (Wi81) list the General Electric Wilmington plant (Table 7-4) as having a capacity of 1500 MT uranium per year. This plant is used as the reference facility (based on E180) and has been specified to have a capacity of 1000 MT uranium per year (E180). However, the facilities at the plant were built large enough to allow for doubling the capacity (E180). Therefore, given the many uncertainties in projecting D&D wastes, it is judged that the increased process capacity does not significantly effect the waste estimates.

The projected 1985 capacities for all the facilities, except those owned by CE, in Table 7-4 are around 1000 MT of uranium per year. Therefore, estimates for the large plants are scaled directly from the reference plant. The D&D wastes for the CE plant process equipment are scaled to the reference facility by using the square root of the ratio of the production capacities. Using the square root of the amount of licensed material as a scaling factor recognizes that large plants are generally more efficient than small plants and that the amount of production equipment in a large plant is proportionally less than that in a smaller plant. The validity of the D&D waste estimates obtained by this technique are within the uncertainties interjected by differences in processes, and plant housekeeping and waste-management practices.

Combining the two B&W plants and two CE plants, and using the square

root scaling factor (the B&W Leechburg plant is assumed to be the same as the reference facility), the facilities in Table 7-4 are equivalent to 5.4 reference facilities. This gives a total of 4300 kg of uranium at shutdown, before inventory cleanout. The distribution of this material in the process equipment can be estimated from Appendix B.

The other uranium fabrication facilities are listed in Table 7-5. The inactive uranium facilities: Kerr-McGee (partially decommissioned), General Electric at San Jose (plant was decontaminated, E180), and the Westinghouse plant at Cheswick (small plant being decommissioned) from Table 7-1 are not listed. The facilities in Table 7-5 all have licenses for high-enriched uranium (greater than 20%) or unspecified enrichment. The Nuclear Fuel Services Plant produces enriched UO_2 for Naval reactor fuel (NN82a). This is probably fabricated into rods at one of the B&W plants and possibly other plants. Because of their diverse and unknown operations, it is hard to estimate the existing contamination for these facilities.

Since plant process capacities are not indicated, the possession license for special nuclear material is used to approximate the size of the facilities. As a rough approximation, the B&W plant in Lynchburg, the Nuclear Fuel Services plant, and the United Nuclear plant at Montville are assumed to be similar to the reference plant. Although these facilities are smaller than the reference facility, it is assumed that the levels of contamination may be similar (because of criticality dangers, it takes more equipment to process a given amount of highly-enriched uranium). The highly enriched uranium will require more isolation facilities (glove boxes) and make it more hazardous and therefore difficult to decontaminate

TABLE 7-5
OTHER URANIUM FUEL FABRICATION FACILITIES
Source: NRC81a

<u>Facility</u>	<u>Material License (kg of U-235)</u>	<u>Comment</u>
Babcock and Wilcox Lynchburg, VA	30,000 - High Enrichment (greater than 20%)	
Babcock and Wilcox Leechburg, PA	55 - High Enrichment	
General Atomic San Diego, CA	990 - Enrichment Not Specified	R&D
General Electric Pleasanton, CA	1,000 - Enrichment Not Specified	
Nuclear Fuel Services Erwin, TN	4,250 - Enrichment Not Specified, but Greater than 20% (NN82a)	Naval Reactor Fuel (NN82a)
Rockwell International Canoga Park, CA	1,500 - Any Enrichment	
Texas Instruments Attleboro, MA	350 - Enrichment Not Specified	Fuel Fabrication
United Nuclear Montville, CT	12,000 - Enrichment Not Specified	Fuel Fabrication
United Nuclear Wood River	850 - Enrichment Not Specified	Uranium recovery, not really fabrication

equipment.

The other facilities in Table 7-5 are scaled to the reference facility using a factor of one-seventh. This factor is derived by classifying them all as less than 1000 kg and using the square root of the ratio of the amount of licensed material in the reference facility (50,000 kg) to that in the given facilities.

The above estimates are only given as rough approximations since these facilities are not part of the LWR fuel cycle.

7.2.2 Existing Contamination

Estimates of the amount of contamination at the reference fuel fabrication facilities are given in Table 7-3. Estimates for LWR fuel fabrication facilities are given in Table 7-6. The estimates are based on the reference facility and the scaling factors provided in Section 7.2.1. At the time of plant shutdown, the total uranium inventory for the eight plants is estimated to be 4,690 kg. The total is based on 4,300 kg in the process equipment and facilities and 390 kg in the lagoons. Estimates for the enriched uranium facilities are not given since they are not directly applicable to this report.

7.2.3 D&D Alternatives and Wastes

The alternatives for D&D were discussed in Section 7.1.3.

7.2.3.1 Volume and Activity of Wastes

The total volume of D&D wastes (includes recyclable material) is 33,000 m³ containing 540 kg of uranium. These values exclude 150,000 m³ of

TABLE 7-6
TOTAL D&D WASTES FOR ALL LWR FUEL FABRICATION FACILITIES

<u>Waste Parameter</u>	<u>Scaling Factor</u>	<u>Material for Facilities</u>	
		<u>Activity (kg of Uranium)</u>	<u>Volume (m³)</u>
U Inventory at Shutdown	5.4 ^b	4,300	-
U Inventory After Inventory Clean-out	5.4	1,500	-
U Inventory After Initial Decontamination	5.4	760	-
Wastes and Materials from D&D			
Final D&D Inventory Uranium	5.4	540	-
LLW	5.4	-	4,300
Unrestricted Waste (excludes recyclable material)	5.4	-	17,000
Recyclable Material (Scrap and Usable Equipment)	5.4	-	12,000
Fluoride Lagoon Sediments	5.1 ^c	390	150,000

a Total for all the facilities listed in Table 7-4.

b Based on Section 7.2.1.

c Based on plant capacities for 1985 from Table 7-4. It is assumed the 1985 capacities will reflect the average lifetime capacity. The accumulation of fluoride wastes is scaled linearly with production.

sediments from the fluoride lagoon which are assumed to be reprocessed. About 35% of the total D&D wastes (33,000 m³) are assumed to be recycled, almost half as reusable equipment.

These estimates are based on extrapolations from the reference facility. There are numerous uncertainties including variations in process equipment and facility housekeeping practices. The management philosophy and financial market conditions at the time of D&D will affect the amount of effort applied to decontaminating and salvaging materials. Furthermore, if the fluoride wastes are not reprocessed, this volume of material will exceed the volume of other LLW by more than an order of magnitude.

7.2.3.2 Chemical and Physical Form

The chemical and physical form of the radioactivity in the wastes is described in Section 7.1.3.2 for the reference facility. The primary radionuclides are U-234 and U-235. The uranium is present in both soluble (valance 6) and insoluble (valance 4) forms.

7.2.3.3 Materials

The composition of the waste and materials from D&D is discussed in Section 7.1.3.3 for the reference facility.

7.2.3.4 Residual Materials

The recyclable materials are listed in Appendix B.

7.3 REFERENCE MIXED OXIDE FUEL FABRICATION FACILITY

Mixed oxide facilities (MOX) contain processes similar to other

fabrication plants, but produce fuel composed of natural or depleted uranium and plutonium (NRC76, Je79). The processes are similar to the gadolinia loop of the uranium fabrication plant in that a proper mixture of the two species is obtained, formed into dioxide pellets, and formed into fuel rods. The purpose of MOX fuel is to use plutonium recovered in the reprocessing of spent fuel. The mixture of plutonium to uranium can vary. A mixture of 23% plutonium and 77% uranium is used by Je79; whereas DOE79a specifies a ratio of 1 kg plutonium per 22 kg uranium, or about 5% and 95%, respectively.

The MOX plants are often associated with the uranium fabrication plants (see Table 7-1). Essentially all the plants are inactive due to the program shift away from the use of MOX fuel.

7.3.1 Description of Reference MOX Facility

Several studies have been done to estimate D&D wastes from MOX plants. Jenkins et al, (Je79) describe a small 2 MTHM/year* MOX facility based on the inactive Kerr-McGee plant at Cimarron, OK. The projected operating life is 10 years. DOE79a describes a 400 MTHM/year facility that will process the plutonium from a 2000 MTHM/year fuel reprocessing plant, and DOE80a also considers MOX plants. NRC81 uses the MOX facility from Je79. NRC76 is an environmental impact statement on the use of MOX fuel.

The facility in DOE79a is basically a dry process facility where PuO_2 and UO_2 powders are blended, formed into pellets, and loaded into fuel rods (DOE79a). The only wet processes are decontamination and scrap recovery. About 2% of the scrap is contaminated such that it has to be

* MTHM/year = Metric tons of heavy metal (uranium and plutonium) per year.

purified prior to recycling into the process stream.

The Je79 reference facility includes both oxide and nitrate feed facilities. Therefore, it includes proportionally more wet chemistry facilities than the DOE79a plant.

The MOX fuel fabrication processes and facilities are similar to those described for the uranium plant in Section 7.1 and Appendix B and are not repeated here.

The reference facility from Je79 will be used to obtain waste estimates.

It is believed to be more indicative of the size of the existing facilities than the larger plant from DOE79a and more detailed information is given. The plant from DOE79a was intended to characterize full-scale production plants if the MOX cycle was adopted. Most of the existing plants are smaller research and development type plants (Je79, NRC81a).

7.3.2 Existing Contamination at Reference MOX Facility

The projected contamination for the reference MOX facility is summarized in Table 7-7. The values for the 400-MTHM/yr facility from DOE79a are also given for comparison. The plutonium inventory of the large DOE79a plant is only twice the inventory of the smaller facility; however, there is some uncertainty on the definition of the values from DOE79a (i.e., are the values for before or after a final inventory clean-out). The relatively small inventory of the DOE79a facility may be due to the lower plutonium-to-uranium ratio for the DOE79a facility than for the Je79 facility (i.e., 0.045 and 0.30, respectively).

TABLE 7-7
REFERENCE MOX FUEL FABRICATION FACILITY

<u>Reference Facility</u>	<u>Parameter</u>	<u>Value</u>
Small MOX Facility (Je79) Capacity: 2 MTHM/year	Inventory at Shutdown	
	Plutonium (kg)	45
	Uranium (kg)	150
	Inventory After Operational Cleanout	
	Plutonium (kg)	23
	Uranium (kg)	78
	Inventory After Decontamination	
	Plutonium (kg)	11
	Uranium (kg)	37
	Wastes from D&D	
Production MOX Facility (DOE79a) Capacity: 400 MTHM/year	LLW (m ³)	270
	TRU (m ³)	160
	Inventory at Shutdown ^a	
	Plutonium (kg)	22
	Uranium (kg)	620
	Wastes from D&D (m ³) ^b	2,800

a DOE79a refers to the inventory at shutdown and does not discuss inventory cleanout. However, the report gives the impression that shutdown may be after inventory cleanout.

b Based on the content of plutonium, this is all TRU waste. The lowest average concentration is 800 nCi/g (DOE79a, Table 8.6.3). The volume is for raw waste--not packaged or compressed.

The final radioactive waste inventory from the reference uranium fuel fabrication facility is proportionally much less than that from the reference MOX facility. Whereas the process capacity of the uranium facility was 500 times that of the small MOX facility, the heavy metal inventory (uranium versus uranium plus plutonium for MOX) was only twice as high.

7.3.3 D&D Alternatives and Wastes

The alternatives for D&D at MOX facilities are similar to those for uranium fuel fabrication facilities (discussed in Section 7.2.3). The wastes are based on DECON, the primary alternative.

There is essentially no D&D experience for commercial facilities, and the results at government facilities have generally not resulted in unrestricted release of the buildings. A partially decontaminated facility at the Argonne National Laboratory is now used by the New Brunswick safeguards laboratory. A facility at Mound was partially decontaminated, but is still a restricted area and is vacant (Je79). However, it is judged that D&D with full decontamination can be accomplished with reasonable effort (NRC81, Je79).

The wastes from D&D of the reference facility were summarized in Table 7-7. These wastes assume that most of the decontamination wastes generated during D&D are processed in the waste process equipment. The volume of wastes from the large model MOX facility of DOE79a are also given for comparison. Based on the calculated average activity in the wastes from the large facility (DOE79a, Table 8.6.3), these are all TRU wastes. The total LLW estimates for the reference uranium fabrication facility

(Section 7.1.3) are only twice the LLW and TRU wastes from the reference MOX facility, even though the uranium facility is much larger.

Table 7-8 provides a general breakdown of the sources of wastes for the reference MOX facility. The primary sources of TRU waste are the glove boxes and unprocessed trash from the D&D operation. The main sources of LLW are decontaminated tanks and the glove boxes.

It is assumed there will be 2900 m³ of waste in the sewage lagoon. The lagoon wastes will weigh about 3500 MT and contain 0.25 g of plutonium (Je79). Assuming the plutonium is all Pu-239, the activity would be 4.3 pCi/g; less than 15 pCi/g, which is relatable to the proposed EPA transuranic guidance (EPA77, EPA77a). However, given the mixture of transuranics in an MOX plant at shutdown, shown in Table 7-9, the average concentration will probably be considerably greater than 15 pCi/g, but will be less than 10 nCi/g (i.e., TRU waste, DOE82).

Contaminating Radionuclides - The mass of the contaminating material will be mostly uranium (natural or depleted in U-235), but the activity will be primarily due to plutonium and Am-241 (decay product of Pu-241). The major fraction of the transuranic activity at shutdown and for the first 50 years is due to Pu-241; however, over 80% of the mass is due to Pu-239 and Pu-240 (DOE79a) (Pu-239 and Pu-240 are usually combined because they cannot be distinguished analytically, except by mass spectroscopy). The relative concentrations and mass contributions of the principal transuranics (based on DOE79a) are given in Table 7-9.

The materials in the D&D wastes for the MOX facility will be similar to those for the reference uranium facility (see Appendix B).

Very little material is projected for recycle from the reference MOX

TABLE 7-8
SOURCES OF WASTE, REFERENCE
MOX FUEL FABRICATION FACILITY
Source: Je79

<u>Source</u>	<u>TRU (m³)</u>	<u>LLW (m³)</u>
Glove Boxes and Hoods	41	94
Tanks and Equipment	6.4	102
HEPA and Roughing Filters	34	-
Concrete Rubble	20	-
Solidified Decon Liquid Wastes	14	-
Trash	49	-
Piping Valves and Duct Work	<u>-</u>	<u>71</u>
TOTAL	160	270

TABLE 7-9
TRANSURANIC ACTIVITY AT A MOX FACILITY^a

Nuclide	At Time of Shutdown		After Shutdown	
	Relative Activity Compared to:		Relative Mass Contribution	Relative Activity Compared to Pu-239/240 ^b
	Pu-239	Pu-239/240 ^b		10 Years 100 Years
Pu-238	13.6	4.48	0.025	4.1 2.1
Pu-239/240		1	0.818	1 1
Pu-239	1	0.33	0.531	0.33 0.33
Pu-240	2.04	0.67	0.287	0.67 0.67
Pu-241	250	82	0.081	52 0.75
Am-241	7.95	2.6	0.075	3.62 4.95

a Relative concentrations of activity based on DOE79a. Radioactive decay data from Wa77.

b Pu-239 plus Pu-240. The activity of these two isotopes is added together because most analytical techniques do not distinguish between them.

facility (Je79). About the only recycled material is from the laboratory.

7.4 MOX FUEL FABRICATION FACILITIES

The MOX facilities from Table 7-1 are listed in Table 7-10. Jenkins et al, (Je79) also list MOX facilities operated by Westinghouse at Anderson, SC (a facility was proposed, but was not built), Getty/Skelly Oil at Erwin, TN (probably now Nuclear Fuel Services), Combustion Engineering at Windsor, CT, and B&W at Lynchburg, VA. Licenses for these plants are no longer listed by NRC81a, and, therefore, they are not listed in Table 7-10. Except to recognize the possibility of their existence, they are not considered. It is doubtful whether any of the facilities will be started up again unless the MOX cycle is used. Given the uncertainties of programs it is impossible to estimate facility lifetimes.

7.4.1 Description of Facilities

Essentially, the only information given on the MOX facilities is the possession limit for special nuclear material (SNM). Based on the SNM limit, all the facilities except for the B&W and General Electric plants are similar in size and fairly small. Presently, essentially all the plants are in an inactive, standby, or partially deactivated status (NRC81a, Je79).^{*} Most of the facilities only operated several years at most. The Kerr-McGee facility, basis of the reference plant, operated five

^{*} Personal communication, R. Thomas, U.S. Nuclear Regulatory Commission, Walnut Creek, CA, June 1, 1982.

TABLE 7-10
MIXED OXIDE FUEL FABRICATION FACILITIES
Sources: Je79, NRC81a

<u>Facility</u>	<u>Amount of SNM (kg Pu)</u>
Babcock and Wilcox Leechburg, PA	1,000
Exxon Nuclear Co. Richland, WA	10
General Atomic San Diego, CA	4
General Electric Pleasanton, CA	150
Kerr-McGee Crescent, OK	11
Rockwell International Canoga Park, CA	3.5
Westinghouse Cheswick, PA	Being Deactivated

years.

7.4.2 Existing Contamination

Estimates of the existing contamination for MOX facilities are based on the reference facility. Since the postulated levels of contamination are based on accumulation of contamination during each year of operation, the use of the estimates from the reference facility should provide conservative results (i.e., results are not scaled for operating time because dates are not given).

Contamination at several of the plants is probably less than for the reference MOX facility. Kerr-McGee has cleaned up the site (ponds and lagoons) at the Crescent (Cimarron), OK, facility and may have decontaminated some of the facilities (Je79, NRC81a). Westinghouse shut down the Cheswick, PA, site in February 1980 and was going to initiate decontamination (NRC81a). Babcock and Wilcox terminated the MOX operations at the Leechburg, PA, site in March 1980 and was to start decontamination (NRC81a). The General Atomics plant in San Diego only had limited contamination and did not really fabricate fuel.*

Given these uncertainties, the average existing contamination at each facility is assumed to be equal to that for the reference facility. Therefore, the total contamination is 140 kg of plutonium--23 kg per plant (after inventory cleanout, but before decontamination) times 6 plants. (The Westinghouse Cheswick, PA, plant is assumed to have been decontaminated.) The activity of the plutonium is indicated in Table 7-9.

* Personal communication, R. Thomas, U.S. Nuclear Regulatory Commission, Walnut Creek, CA, June 1, 1982.

There will also be about 78 kg of uranium in each plant. Each plant is also assumed to have a sewage lagoon containing 2930 m³ of sludge with 0.24 g of plutonium.

7.4.3 D&D Alternatives and Wastes

The alternatives for D&D of MOX plants are similar to those given for uranium fuel fabrication plants in Sections 7.1.3 and 7.2.3 and have been summarized in Section 7.3.3. Based on the rationale given in Section 7.4.2, the D&D wastes are based on a direct scaling from the reference MOX facility. These wastes are given in Table 7-11. The volume of the sewage lagoon sediments is included in Table 7-11, even though the level of contamination and disposition of these wastes is uncertain.

The isotopic breakdown of the activity and the types of materials are discussed in Section 7.3.3 and are not repeated here.

TABLE 7-11
D&D WASTES FOR MOX FUEL FABRICATION FACILITIES

<u>Parameter</u>	<u>D&D Wastes From Reference MOX Facility</u>	<u>D&D Wastes From Six MOX Facilities</u>
Inventory After Initial Decontamination		
Plutonium (kg)	11	66
Uranium (kg)	37	220
Wastes		
LLW (m ³)	270	1,600
TRU (m ³)	160	960
Sewage Lagoon (m ³)	2,930	18,000

8. COMMERCIAL FUEL REPROCESSING PLANTS

Three commercial reprocessing facilities have been built in the United States: the Western New York Nuclear Services Center, the Barnwell Nuclear Fuel Plant, and the Midwest Fuel Recovery Plant. Only the New York plant has been operated. The Midwest facility is inoperable as a reprocessing plant, but is now being used to store spent fuel, and the fate of the Barnwell facility is yet to be determined.

This chapter gives estimates of the D&D wastes from these three facilities. The wastes for the two unoperated plants are based on postulated operations. The Western New York facility is considered in the greatest detail since it has been operated.

8.1 THE WESTERN NEW YORK NUCLEAR SERVICES CENTER

The Western New York Service Center (West Valley) at West Valley, New York, was operated by Nuclear Fuel Services, Incorporated (NFS) on land leased from New York State from 1966 to 1972, reprocessing approximately 640 MT of spent fuel (DOE78). In 1969, NFS initiated a program to modernize the plant and to increase the operating capacity from 300 to 750 Metric Tons of heavy metal (MTHM) per year. The objectives of this program were to improve the plant's competitive position vis-a-vis the Midwest and Allied General Nuclear Services' facilities and to meet changing regulatory requirements.

In 1971 a low-level liquid waste treatment facility was installed. This facility operated from May 1971 to the cessation of the West Valley operations in 1972.

In 1973 the AEC set seismic and geologic criteria for nuclear reactors (AEC73). These criteria were also applied to fuel reprocessing plants. In 1974, new requirements on the shipment of plutonium were established. Nuclear Fuel Services estimated that it would cost over 500 million dollars to bring the West Valley facility into compliance and in 1976 decided not to renew its lease from the State of New York. The plant was then shut down. Nuclear Fuel Services maintained the site until February 1982 when Westinghouse Electric Corporation took over operations as the DOE contractor (NN82) responsible for a high-level waste demonstration project (DOE81b). The DOE is responsible to:

- Solidify, in a form suitable for transportation and disposal, the high-level radioactive waste at the center;
- Develop containers suitable for the permanent disposal of the high-level radioactive waste;
- Ship the solidified waste to a Federal facility for permanent disposal as soon as feasible;
- Dispose of the low-level radioactive wastes produced during the solidification process; and
- Remove all radioactivity from tanks, facilities, and any material and hardware used in connection with the project.

The responsibility for the site will revert back to New York state when the project is completed.

The execution of the above project will impact the actual volumes of D&D wastes when the site is decommissioned in the future. For this reason two assumptions have been made in the present study. First, D&D wastes estimates are based on preproject conditions as described in DOE78. Second, all reprocessing wastes have been removed and their volume is not considered to be part of the D&D wastes.

8.1.1 Facility Description

The Purex process was used for reprocessing of spent nuclear fuel at West Valley (Be81, DOE78). The design capacity of the plant was 300 MTHM/year.

Spent fuel assemblies were transported to the plant in heavily shielded casks. Road dirt was removed by spray washing and the assemblies were unloaded. Once unloaded the fuel assemblies were stored under water in aluminum canisters for a minimum 150 day cooling period before reprocessing.

The head-end processes were mechanical and consisted of separating fittings and casings from the assemblies and then chopping the zircaloy or stainless steel fuel rods into short pieces, exposing the spent fuel. The fuel material was transferred to one of two annular batch dissolvers where fuel was dissolved with nitric acid. The zircaloy and stainless steel cladding was not dissolved. The dissolved product containing uranium, plutonium, other actinides and fission products was then directed to the partition cycle. Here, four pulsed countercurrent extraction columns were used to separate the uranium and plutonium from the fission products and other actinides. The uranium and plutonium were then separated from one another. The uranium product stream was then purified via two additional solvent extraction cycles, each using two pulsed countercurrent columns. The final uranium product was a uranyl nitrate solution. The plutonium product stream was purified once via solvent extraction (two pulsed columns) and finally by ion exchange. The final plutonium product was a plutonyl nitrate solution.

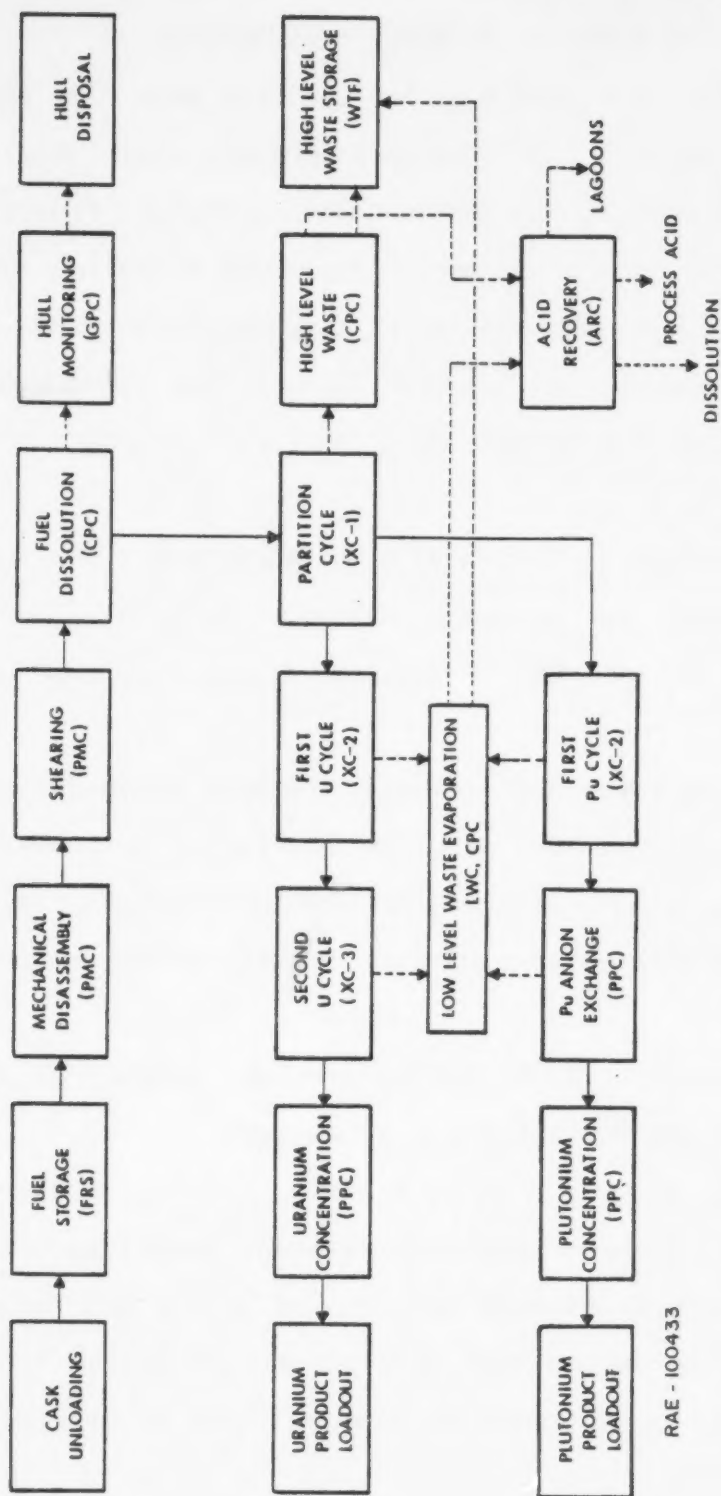
The acidic high activity wastes from the partition cycle contained almost all of the fission products and actinides other than uranium and plutonium. These wastes were evaporated both to concentrate the wastes and to recover the nitric acid for reuse. The concentrator bottoms were then neutralized and pumped to underground cooled carbon steel tanks. Neutralizing the wastes resulted in eventual sludge formation within the tanks. Intermediate and low activity aqueous wastes were also concentrated, neutralized and pumped to the tank farm. A flowsheet, from DOE78, for the West Valley Purex process is given in Figure 8-1.

Another process run in a single campaign was the Thorex process (Be81). Approximately 16 MT of thorium-enriched uranium fuel were reprocessed. The liquid wastes from this process were not neutralized, because the thorium would have precipitated with the sludge.

Major structures at West Valley requiring decontamination include the fuel receiving and storage area, the main process building, the tank farm and the low-level waste treatment facility (DOE78). In addition, the plant laundry will require decontamination. The estimates of existing contamination and D&D wastes do not include the 165 MT of spent fuel presently stored at the facility (NN82b). This fuel was originally scheduled for reprocessing at the plant.

Fuel Receiving and Storage Area - The fuel receiving and storage area (FRS) is adjacent to the main process building. The FRS includes the cask decontamination room, the cask unloading pool, a 90 metric ton capacity unloading crane, the fuel storage pool, and pool water cooling and purification equipment.

The cask decontamination room is approximately 4.3 m by 4.3 m by 9 m



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FIGURE 8-1. WEST VALLEY PUREX PLANT.

high. It is constructed of stainless steel and aluminum. The decontamination room was added as a part of the modification program.

The cask unloading pool is 6 m by 7 m and 13 m deep. The pool is constructed of concrete, and it is lined with stainless steel. There is a shelf 8.8 m below the surface. The pool contains a canister lift rack used to lower empty aluminum storage canisters to the bottom of the deep section of the pool. After the canisters are loaded, they are placed on the shelf, using the 0.9 MT capacity fuel transfer hoist. From there they are transferred to the fuel storage pool using the 1.8 MT capacity fuel pool canister crane.

The fuel storage pool is 23 m by 12 m and 8.8 m deep. This pool is constructed of concrete and is coated with carbaloy paint. The fuel storage pool is equipped with fuel storage racks having a capacity for 924 storage canisters.

The fuel receiving and storage area water treatment system consists of a 32 liter/second diatomaceous earth filter and a 6 liter/second nonregenerable ion exchanger. The original pool cooling system has been replaced with a dual evaporation system with a total cooling capacity of 12×10^6 Btu/hr.

Transfer of canisters to the process area was accomplished via a swing-arm conveyor at the west end of the storage pool.

The Main Process Building - The main process building, a five floor structure, was used for the head-end, extraction and product purification processes. Other related processes were carried out in this building, including aqueous waste concentration, acid recovery and solvent recovery. The main process cells in the process building are listed in Table 8-1.

TABLE 8-1
 DIMENSIONS OF CELLS DIRECTLY INVOLVED IN
 FUEL REPROCESSING AT WEST VALLEY
 Source: DOE78

<u>Cell</u>	<u>Dimensions (m)</u>		
	<u>Width</u>	<u>Length</u>	<u>Height</u>
PMC	3.7	15.8	7.6
GPC	3.4	13.9	5.9
SRR	3.0	11.6	4.0
EDR	7.9	9.4	7.6
CPC	6.7	28	13.1
XC-1	5.0	4.9	16.8
XC-2	6.3	6.4	17.5
XC-3	6.5	4.8	17.7
PPC	4.9	6.1	17.4
LWC ("L" shaped)	4.9	19.2	5.8

Several cells were dedicated to head-end processes. The process mechanical cell (PMC) contains a saw and push ram for separating the fuel assemblies from the casings and a shear blade for chopping the assemblies. Sheared fuel is collected in the general process cell (GPC) prior to dissolution. The GPC was also used to store and package scrap (e.g., leached cladding hulls, prior to burial). Major equipment items include a 1.8 MT capacity crane and a power manipulator. The scrap recovery room (SRR) was used to transfer leached hulls from the GPC to casks for delivery to the waste burial area. The equipment decontamination room (EDR) and the GPC crane room (not shown in Table 8-1) were used for equipment decontamination and maintenance. Other head-end cells not shown in Table 8-1 are the mechanical crane room (MCR), used for equipment maintenance, and the manipulator repair room (MRR).

The chemical process areas include: the chemical process cell (CPC), three solvent extraction cells (XC-1, XC-2, XC-3), the product purification cell (PPC), the liquid waste cell (LWC), and the acid recovery cell (ARC). The CPC, used for the dissolution of the spent fuel elements, contains two 4,000 liter stainless steel annular dissolvers, a 9,000 liter extraction feed adjustment and accountability tank, two waste evaporators, and two cranes. The XC-1 cell contains four pulsed columns used in the uranium-plutonium partition cycle and tanks for the collection of that cycle's high-level liquid waste. The XC-2 cell contains the 1st plutonium cycle and 1st uranium cycle pulsed columns and the No. 1 and No. 2 solvent cleanup systems--each consisting of two packed wash columns and a solvent washing vessel. The XC-3 cell contains equipment for the 2nd uranium cycle and the No. 3 solvent cleanup system. The LWC contains tanks where waste

liquids were stored prior to evaporation (CPC). The ARC contains an acid fractionating column where nitric acid was recovered from the waste evaporator overheads.

Waste Tank Farm - The waste tank farm consists of four underground tanks--8D1, 8D2, 8D3, and 8D4. The 8D1 and 8D2 tanks are very similar in structure as are the 8D3 and 8D4 tanks.

The 8D2 tank is currently used to store approximately 2.1 million liters of neutralized Purex wastes. Plans are currently underway to remove and solidify these wastes. The 8D1 tank is a spare and has not been used.

The tanks are 21 meters in diameter and 8 m high. They are constructed of 1.1 to 1.3 cm thick carbon steel plate. Each tank rests on a 30 cm layer of perlite block which rests on 7.6 cm of pea gravel which is contained in a carbon steel pan. The pan rests on a second 7.6 cm layer of pea gravel on the 69 cm thick concrete vault floor. The vault floor rests on a 10 cm thick leveling slab on top of 1.2 m of saturated pea gravel. Each vault roof is supported by the walls and six concrete columns contained in steel columns (76 cm diameter), which penetrate the tank. A 23 cm annular air space was left around each concrete column. The 8D2 tank also contains four air lift circulators and a steam heat exchanger.

The smaller tanks, 8D3 and 8D4, are located in a single reinforced concrete vault 9.8 m by 9.8 m with a height of 7.7 m. The vault is lined with stainless steel to a height of 46 cm and the tanks are constructed of stainless steel. At present 45,000 liters of acidic Thorex waste are stored in 8D4 and 8D3 is an unused spare. Tank internals include two side mounted cooling coils and one bottom cooling coil in each tank.

Low-Level Waste Treatment Facilities - The low-level waste treatment facilities (LLWT) consist of the LLWT building and a system of neutralizer-interceptor lagoons. Equipment in the LLWT building consists of a 64,000 liter stainless steel flocculator-clarifier, an anthracite filter, and an ion-exchange system. The lagoon network consists of a 1900 liter neutralizer pit, two 87,000 liter interceptors and five lagoons with capacities of 1,100, 9,500, 12,500, 760, and 750 cubic meters. The neutralizer pit and interceptor are constructed of concrete with stainless steel linings; the 760 m³ lagoon is constructed in the silty till, and has a rubber lining. The remaining lagoons are constructed in the native silty till and are unlined.

8.1.2 Existing Contamination

At present the highest levels of contamination at West Valley are associated with the waste tanks 8D2 and 8D4 which contain 3.3×10^7 and 2.4×10^6 Ci, respectively (DOE78). Tables 8-2 and 8-3 taken from DOE78 show the nuclide inventory estimates for the neutralized 8D2 Purex waste. Of the major isotopes present, the Cs-137 and Ba-137m are in the supernate and the Sr-90, Y-90, and actinides are in the sludge at the bottom of the tank. The estimated nuclide inventory in the Thorex waste is given in Table 8-4.

The other highly contaminated area is the main process building. Exposure rates in the process areas of this facility are given in Table 8-5. As expected the highest radiation levels are in the head-end process areas, the CPC (dissolution and high activity waste evaporation), and the XC-1 (partitioning cell). Radiation levels in support areas range

TABLE 8-2
ESTIMATED FISSION PRODUCT INVENTORY

WEST VALLEY, TANK 8D2^a
Source: DOE78

<u>Isotope</u>	<u>Curies</u>
Sr-90	7.6x10 ⁶
Y-90	7.6x10 ⁶
Zr-93	250
Tc-99	1900
Ru-106	550
Rh-106	550
Sb-125	1.1x10 ⁴
Cs-134	3.9x10 ⁴
Cs-137	9.0x10 ⁶
Ba-137m	8.4x10 ⁶
Ce-144	330
Pr-144	330
Pm-147	1.1x10 ⁵
Sm-151	2.0x10 ⁵
Eu-152	450
Eu-154	1.5x10 ⁵
TOTALS	3.3x10 ⁷

^a Long-lived radionuclides producing less than one watt of decay heat are excluded.

TABLE 8-3
ESTIMATED ACTINIDE ELEMENT INVENTORY^{a,b}

WEST VALLEY, TANK 8D2
Source: DOE78

<u>Isotope</u>	<u>Half-Life^d (years)</u>	<u>Curies</u>
Np-237	2,140,000	23
Pu-238	87.7	1,660
Pu-239	24,000	1,800
Pu-240	6,500	970
Pu-241	15	34,500
Pu-242 ^c	376,000	0.7
Am-241	430	18,600
Am-242m ^c	152	190
Am-243	7,400	220
Cm-242	0.45	--
Cm-244	18	9,200
Cm-245	8,500	1
Cm-246	4,700	<u>0.2</u>
TOTALS (Rounded off)		68,000

a Estimate for 1985.

b Uranium not included. It has been estimated that approximately 2500 kg of unrecovered uranium from the Purex process are in the tank.

c Np-239 (2.35 days) and Am-242 (16 hours) are in equilibrium with Am-243 and Am-242m, respectively. These inventories are included in the total.

d Based on Wa77.

TABLE 8-4
ESTIMATED THOREX WASTE INVENTORY

WEST VALLEY, TANK 8D4
Source: DOE78

<u>Nuclide</u>	<u>Activity (Ci)</u>
Thorium	3.55
Uranium	0.01
Fission products (include cesium, 7.47×10^5 Ci, and strontium, 4.83×10^5 Ci)	2.43×10^6

TABLE 8-5
EXPOSURE RATES IN THE WEST VALLEY PROCESS CELLS
Source: DOE78

<u>Location</u>	<u>Radiation Level, (mR/hr)</u>
Process Mechanical Cell	1.5×10^5
General Purpose Cell	1.2×10^6
Chemical Process Cell	2.2×10^4
Extraction Cell I	1×10^4
Extraction Cell II	32-140
Extraction Cell III	3-17
Product Purification Cell	0.5
Uranium Product Cell	0.5

from 0.5 mR/hr to 200 mR/hr. The estimated inventory in the main process building is shown in Table 8-6.

Areas at West Valley which are contaminated at low levels include the low-level waste treatment system and laundry. Of these two only the former should contribute significant volumes of D&D wastes.

8.1.3 D&D Alternatives & Waste

Only the DECON and SAFSTOR options are feasible for West Valley and are considered here. In both cases it is assumed that the neutralized Purex waste and Thorex waste have been removed from the tank farm.

Mechanical and chemical decontamination of the facilities is carried out for both options. As a result of the 1969 plant modernization program some areas in the process building have been partially decontaminated and it is difficult to quantitatively ascertain the levels of contamination that would remain after chemical decontamination efforts. For the purposes of this study, however, it is assumed that mechanical and chemical decontamination efforts reduce the current activity in the process building by a factor of ten. The Thorex waste tank, 8D4, is assumed to have a residual activity of 2400 Ci after the waste is removed and 240 Ci after the final chemical flush.

The existence of sludge in the 8D2 tank and the existence of internal structures in this tank complicates decontamination efforts. It has been estimated (DOE78) that 90% of the sludge can be removed mechanically (e.g., by hydrosluicing) prior to the chemical treatment which will remove more than 90% of the amount of remaining waste. As a result, 184,000 Ci of activity are assumed to remain in the tank. Activity levels remaining at

TABLE 8-6
ESTIMATED CURRENT INVENTORY IN THE WEST VALLEY MAIN PROCESS BUILDING
Source: DOE78

<u>Areas</u>	<u>Inventory (curies)</u>	
	<u>Alpha</u>	<u>Beta-Gamma</u>
Mechanical processing cells (PMC & GPC)	90	9,000
Chemical processing cells (CPC, XC-1, PPC)	38	2,700
Process support areas	70	4.4
Personnel access areas	<u>0.02</u>	<u>0.17</u>
TOTAL (Rounded off)	200	12,000

the facility after the decontamination phase are summarized in Table 8-7. The residual activity associated with the facility is about 184 kCi. However, this does not include about 1,840 kCi associated with decontaminating the tanks.

The DECON mode D&D waste estimates are summarized in Table 8-8. Except for the trash and the solidified decontamination solution, all estimates are taken from DOE78. The trash and solidified decontamination solution estimates are obtained as follows. Approximately 3.8 million liters of low-level decontamination solution will be produced in decontaminating the main process building, FRS, and LLWT system (DOE78). A fraction of this material (190,000 liters) is assumed to be used in the initial chemical decontamination of the waste tanks, producing high activity solution waste. Assuming a ten fold volume reduction as a result of solidification, 360 m³ of low-level and 19 m³ of high-level waste are produced. An additional 750 m³ of low activity trash are assumed to be produced.

The SAFSTOR option is assumed to produce the same amount of trash and solidified decontamination wastes as the DECON mode.

8.2 THE BARNWELL NUCLEAR FUEL PLANT

The Barnwell Nuclear Fuel Plant (Barnwell), located at Barnwell, SC, was built by Allied-General Nuclear Services. With the exception of the plutonium conversion facility and the waste solidification facility, the plant was essentially completed by 1977, at which time commercial reprocessing in the United States was indefinitely suspended (Be81).

TABLE 8-7
ACTIVITY LEVELS AT WEST VALLEY AFTER CHEMICAL DECONTAMINATION^a

<u>Area</u>	<u>Activity Curies</u>
Fuel Receiving and Storage	50
Main Process Building	
PMC & GPC	910
Chemical processing cells	275
Support areas	7
Tank Farm	
8D2 tank	184,000
8D4 tank	243
LLW Treatment System	<u>50^b</u>
TOTAL (Excludes activity in tank decontamination solution) ^a	186,000
TOTAL less tank farm	1,300

a Chemical decontamination solutions from tank farm contain approximately 1,840,000 Ci.

b Assumed.

TABLE 8-8

WEST VALLEY D&D WASTE FOR THE DECON MODE

<u>Source</u>	<u>Volume of Wastes (m³)</u>		
	<u>Low-Level</u>	<u>Transuranic</u>	<u>High-Level</u>
Main Process Building, Fuel Storage, and Receiving	700	140	16
LLW Treatment System	1,700	--	--
Tank Farm	1,000	--	57
Trash and Solidified Decontamination Solutions*	<u>1,100</u>	<u>--</u>	<u>19</u>
TOTALS	4,500	140	92

* See text.

At this time it is not known whether or not the plant will be completed and operated and, if so, in what capacity. For example, a 1982 DOE report states that, "Because of fundamental philosophical, dimensional and fabrication details of the design, full scale operation of the plant (Barnwell) would be accompanied from the moment of startup by inordinately high operation and maintenance risks" (RE82).

Since the future use of Barnwell is uncertain and a previous in depth study of the D&D of Barnwell has been written (Sc77), the discussion here is limited to a brief summary of the results of the latter work.

8.2.1 Facility Description

Barnwell was designed to reprocess fuel from commercial light water reactors via the Purex process (Be81). A detailed description of the Purex process as applied to the 1500 MTHM/year Barnwell facility is contained in Sc77 and Be81. A detailed description of the facilities is given in Sc77.

8.2.2 Existing Contamination

As stated above, Barnwell was used as a reference case for a reprocessing plant decontamination and decommissioning study (Sc77). Estimates were made of the residual radioactivity that would remain within the plant after final operational flushing, and after chemical decontamination. These estimates are summarized in Table 8-9 and include a waste solidification facility but not a plutonium conversion facility. These numbers are hypothetical; the facility has not been used.

8.2.3 D&D Alternatives and Wastes

The D&D wastes for the DECON and SAFSTOR modes for Barnwell are given

TABLE 8-9

SUMMARY OF ESTIMATED HYPOTHETICAL RESIDUAL RADIOACTIVITY AT BARNWELL
Source: Sc77

<u>Source</u>	<u>Activity After Final Operational Flush (Ci)</u>	<u>Activity After Chemical Decontamination (Ci)</u>
Main Process Building	144,000	7,000
Tank Farm	30,000,000	10,000
Waste Solidification Plant	11,000	5,000
Auxilliary Service Areas	<u>20</u>	<u>10</u>
TOTAL (Rounded off)	30,000,000	22,000

TABLE 8-10

HYPOTHESIZED RADIOACTIVE WASTES FROM DECOMMISSIONING BARNWELL
Source: Sc77

<u>Disposition of Waste</u>	<u>DECON</u>		<u>SAFSTOR</u>	
	<u>(m³)</u>	<u>(Curies)</u>	<u>(m³)</u>	<u>(Curies)</u>
Deep Geologic Disposal (TRU & HLW)	4,600	2.5x10 ⁷	210	2.5x10 ⁷
Shallow Land Burial (LLW)	<u>3,100</u>	<u>4x10³</u>	<u>180</u>	<u>1x10³</u>
TOTALS	7,700	2.5x10 ⁷	390	2.5x10 ⁷

in Table 8-10 (Sc77). Again, these are hypothetical since the facility has not been used and there are not definite plans for its use.

8.3 MIDWEST FUEL RECOVERY PLANT

The Midwest Fuel Recovery Plant (Midwest) at Morris, Illinois, was built by the General Electric Company to process 1 MT/day irradiated low-enriched uranium fuel using the Aquafluor process (Be81, GE66). The plant was never used for that purpose because of the inability to maintain on-stream, continuous operation in runs on unirradiated fuel. The fuel storage and waste storage areas of the facility were subsequently modified (GE75) and are currently used for the storage of spent fuel.

8.3.1 Facility Description

Though attempts were made to process unirradiated fuel and some uranium contamination likely exists in the process building, this contamination is assumed to be minimal (Be81). Therefore, those areas where spent fuel is currently stored are of more direct interest.

The fuel receiving and storage area has several components: the fuel storage basin, the waste storage basin, the cask unloading pool, the cask decontamination pool, the fuel basin pump and filter rooms, and the manipulator repair area (GE66, GE75).

The fuel storage basin has an area of about 92 m² and is filled with water to a depth of 9 m. The waste storage basin is adjacent to and connected with the fuel storage basin and is of similar size and construction. Both basins now contain fuel storage racks and are used for the storage of

spent fuel assemblies. The cask unloading pool is approximately 3 m by 4.2 m by 15 m deep and is used to unload fuel assemblies from casks prior to storage in the fuel storage basin and waste storage basin. Casks are decontaminated on the cask decontamination pad.

Both basins are cooled using the 7.5×10^6 Btu/hr waste basin cooling system. There is a backup cooling system. Water from the basin is cleaned via circulation through a Powdex filter and a mixed-bed cation-anion exchange demineralizer. The Powdex filter is cleaned by backwashing, and the spent exchange resin is discharged to a low activity vault and replaced.

8.3.2 Existing Contamination

Based on previous work, Sc77, it is estimated that much less than 100 Ci of activity will remain after the chemical decontamination of the fuel storage facilities. Any uranium contamination in the process areas due to trials with unirradiated fuels is assumed to be minimal and for the most part restricted to the interior of the process equipment. Therefore, chemical methods are expected to be quite effective in decontaminating the equipment (E181).

8.3.3 D&D Alternatives and Waste

Using the results of Sc77 as a guide, the volume of waste produced in the complete dismantlement of the fuel storage facilities at Midwest will be approximately 300 m³. This waste will be low-level waste.

The deposition of equipment in the process areas is difficult to determine at this time, and waste volume estimates range from 10 m³ to

1000 m³. Any D&D wastes arising from this source will be low activity. If there is a use for the equipment and if it is cost effective, essentially all of this material can be decontaminated for unrestricted release.

9. SUMMARY

This report provides information to characterize uranium fuel cycle facilities (excluding reactors), estimates of levels of contamination in the facilities at the time of shutdown, and estimates of the activity and wastes associated with decommissioning and decontamination (D&D) of the facilities. The estimates in this document are based on information in the open literature, supplemented by personal communications. Engineering judgement has been used where necessary to fill voids in the information. For most facilities, reference facilities based on published literature are used to characterize the plants and associated D&D wastes.

The categories of facilities covered and a summary of the waste volumes and activities associated with D&D are listed in Table 9-1. Lists of the individual facilities are given in the respective chapters of this report. Both active and inactive facilities are covered in the report, but the only inactive facilities included in Table 9-1 are inactive mines.

The largest volumes of wastes are associated with uranium mines (i.e., over 10^9 m³). There has been minimal D&D of mines and there are no official classifications or standards for mine wastes. Although there is some question regarding the proper classification of the mine wastes, the associated levels of activity generally exceed the standards for unrestricted material that are being developed for uranium mill tailings (EPA80, EPA80a, EPA81). The amounts of uranium or other radionuclides associated with the mine wastes are not given in the table because of the wide range of values. However, based on an average concentration of 50 pCi/g of U-238, the total mine wastes are estimated to contain 1.1×10^5 Ci

TABLE 9-1
SUMMARY OF D&D WASTES FROM URANIUM FUEL CYCLE FACILITIES

Wastes Associated With D&D						
Facility Category	Number of Facilities	Inventory of Radioactivity		Volume of Waste (10 ³ m ³)		
		Uranium (kg)	Other (Ci)	Radioactive		Unrestricted
				LLW	TRU	
<u>Uranium Mines</u>						
		(a)	(a)			
Active Mines						
Surface	52			360,000 ^a		
Underground	303			12,000 ^a		
Inactive Mines						
Surface	1246			750,000 ^a		
Underground	2031			10,000 ^a		
<u>Uranium Mills</u>						
Conventional Mills	24		140	180,000		
			(Ra-226) ^b			
Solution Mining	11		0.2	40		
			(Ra-226) ^b			
Heap-Leach Mining	2		0.8	3,400		
			(Ra-226) ^b			
<u>Uranium Conversion</u>						
	2					
Plant Facilities		5,400		2.6		
Waste Lagoons		74,000	2	54		2.8
			(Th-230)			
			0.2			
			(Ra-226)			
<u>Uranium Enrichment</u>						
	3	15,000		90 ^c		570 ^c
<u>Fuel Fabrication</u>						
LWR Fuel	8					
Plant Facilities		540		4.3		29
Fluoride Lagoon		390		150		
Sediment						
Mixed Oxide Fuel	6	220		1.6	0.96	
Plant Facilities		(66 kg Pu)				
Sewage Lagoons				18 ^e		
Fuel Reprocessing	1		2x10 ⁶	4.5	0.14 ^f	
(West Valley only)						

- a Does not include contaminated surface area around ore stockpiles or ore waste piles. The total area involved is estimated to be 880 km², most of which is at inactive surface mine (open-pit) sites (see Table 3-11). The concentrations of U-238 and its decay products are expected to average about 50 pCi/g.
- b Equal activities of Th-230 and the appropriate decay products of Ra-226 are also present for the conventional mills and heap-leach facilities. Some uranium is also present, but at lower concentrations.
- c This does not include waste buried on site and in waste lagoons.
- d Most of the mass of radioactive material in an MOX plant is uranium, but most of the activity and the limiting contaminant is plutonium.
- e The sludge contains 0.5 g of plutonium.
- f There is also 92 m³ of high-level waste.

of U-238 and each of the associated U-238 decay products (e.g., Th-230 and Ra-226). The above curie content of U-238 is also equivalent to 3.4×10^5 MT of uranium.

The greatest amount of activity--about 2 million curies--and the highest specific activities are associated with the wastes from fuel reprocessing. The fuel reprocessing estimates in the table are only for the Nuclear Fuel Services West Valley plant in New York. Estimates for postulated D&D of Midwest and Barnwell plants, which have not operated, are greater (see Chapter 8).

The most common contaminant at fuel cycle facilities is uranium. It is the primary contaminant for conversion plants, enrichment plants, and fuel fabrication plants. Uranium is also present in the mine, mill and reprocessing plant wastes but its health significance is generally secondary to the other radionuclides which are present (e.g., Th-230, Ra-226 and associated Rn-222, long-lived fission products and transuranics at the reprocessing plants).

For several of the facility categories listed in the table, wastes and sediments from lagoons are listed separately. The volumes and sometimes the activities in the lagoon wastes are considerably greater than the D&D wastes from the processing facilities. The lagoon wastes are listed separately so that the process wastes can be identified. Also, the lagoon wastes may contain economically recoverable quantities of uranium (and possibly some chemicals). Therefore, the lagoon wastes may represent recoverable material. However, whether they are reprocessed will depend on actual concentrations and market conditions at the time of plant shutdown and D&D.

The activity and volume estimates for D&D wastes from many of the facilities (e.g., uranium conversion, fuel fabrication, and enrichment) assume that most of the decontamination solutions and materials are processed through the normal plant systems to recover the uranium and reduce the volume. The validity of this assumption depends on the market conditions, value of uranium, and cost of waste disposal at the time when plant shutdown and D&D takes place. The estimates of contamination and wastes have generally been based on a process of scaling from reference facilities. Differences between facilities, lack of information on facility process capacities, differences in waste management and house-keeping practices, etc., will cause large variations in estimates of wastes. Therefore, the uncertainties associated with the estimates should be recognized.

APPENDIX A

The active uranium mines as compiled by the Environmental Protection Agency (EPA82) are listed in Table A-1. The number of mines listed (321) is less than the number specified by DOE81a. However, this listing, based on DOE79, DOI79, and DOL79, is the best available listing of individual locations. Although the names of several mines appear to be almost identical, giving an indication of double listing, unique mine location numbers indicate that they are separate locations.

The following headings are used:

Mine Name

Names given by DOI79. Mines are sorted by state, county, and mine name.

County

County where mine is located as given by DOI79.

Mining Method

As specified by DOI79.

TABLE A-1
ACTIVE URANIUM MINES
Source: EPA82

<u>Mine Name</u>	<u>County</u>	<u>Mining Method</u>
*** ALASKA		
Valdez Creek	Healy	Placer
Cache Creek	Talkeetna	Placer
Poorman Creek	Talkeetna	Placer
*** ARIZONA		
Twin Buttes	Pima	Surface
*** CALIFORNIA		
Little Sparkler Mine	Inyo	Undergr
Miracle Mine	Kern	Undergr
*** COLORADO		
Lewis C Mundy Claim	Custer	Surface
Blue Eagle Mine	Dolores	Unknown
Falcon	Dolores	Undergr
Sunset	Fremont	Undergr
Rifle Mine	Garfield	Undergr
Black Knight	Jefferson	Surface
Hoffmeister Uranium Prospect	Jefferson	Surface
Schwartzwalder Mine	Jefferson	Undergr
Shepherd Mine	Jefferson	Surface
Lewis Mountain	La Plata	Undergr
Arrowhead 8	Mesa	Surface
Austin Mine	Mesa	Undergr
Beth B & Kelly Rock Claims	Mesa	Surface
Black Mama	Mesa	Undergr
Calamity #10,11,13,17,18,19,20,21	Mesa	Surface
Calamity Group	Mesa	Surface
Cambell #2	Mesa	Surface
Cedar Cliff Muskrat et al. Claim	Mesa	Surface
Economy	Mesa	Undergr
La Sal	Mesa	Undergr
La Sal 4	Mesa	Undergr
New Verde	Mesa	Undergr
October Adit	Mesa	Undergr
Outlaw 23	Mesa	Undergr
Outlaw Group Mine	Mesa	Undergr
Rajah 30	Mesa	Undergr
Rajah 11&63	Mesa	Undergr

TABLE A-1 (Continued)

<u>Mine Name</u>	<u>County</u>	<u>Mining Method</u>
*** COLORADO (cont.)		
Rajah 49	Mesa	Undergr
Rajah Group Mines	Mesa	Undergr
Rodger Group	Mesa	Undergr
Thorton Tunnel	Mesa	Undergr
Tec Open Pit A thru L	Moffat	Surface
Black Dinah Mine & Dump	Montrose	Undergr
Bliss	Montrose	Undergr
Bliss Mine	Montrose	Undergr
Coloradian	Montrose	Undergr
Diana Mine	Montrose	Undergr
Eula Belle	Montrose	Undergr
Fawn Springs #9	Montrose	Undergr
Fawn Springs No 5	Montrose	Undergr
Firebird Mine	Montrose	Undergr
Fourth Of July	Montrose	Undergr
Geo No. 1	Montrose	Undergr
Geo No. 7	Montrose	Undergr
Ground Hog Mine	Montrose	Undergr
Happy Mine	Montrose	Undergr
J.M. Mine	Montrose	Undergr
Jo Dandy Mine	Montrose	Undergr
King Solomon	Montrose	Undergr
Last Chance #3	Montrose	Undergr
Lexington	Montrose	Surface
Little Fawn #1	Montrose	Undergr
Long Park No. 15	Montrose	Undergr
Merry Widow	Montrose	Undergr
Mineral Joe Group	Montrose	Undergr
Mineral Joe No 2	Montrose	Undergr
Mum	Montrose	Undergr
Nil	Montrose	Undergr
Nil-Trace Group Mines	Montrose	Undergr
Ophir Mine	Montrose	Undergr
Peanut #2	Montrose	Undergr
Peggy No. 2	Montrose	Undergr
Pickett Corral	Montrose	Undergr
Radium Hill	Montrose	Undergr
Radium Hill No. 10	Montrose	Undergr
Rattlesnake	Montrose	Undergr
Rex 38 Mine	Montrose	Undergr
Rim Rock Blues Group	Montrose	Undergr
September Morning Mine	Montrose	Undergr

TABLE A-1 (Continued)

<u>Mine Name</u>	<u>County</u>	<u>Mining Method</u>
*** COLORADO (cont.)		
Silver Dollar #1	Montrose	Undergr
St. Patrick No. 7	Montrose	Undergr
Sunbeam Group	Montrose	Undergr
Sunbeam Group Mines	Montrose	Surface
Uravan Mine	Montrose	Undergr
V.C.A. Mill Tailings	Montrose	Surface
Wedge 1	Montrose	Undergr
Camp Bird Mine	Ouray	Undergr
Revenue	Ouray	Undergr
London	Park	Undergr
North London Mine	Park	Undergr
Midnight	Rio Blanco	Undergr
Alice C-SR-15	San Miguel	Undergr
Alice No. 2 LC-SR-IS	San Miguel	Undergr
Ann (C-SR-16)	San Miguel	Undergr
Bell No. 1	San Miguel	Undergr
Brighton (C-SR-11)	San Miguel	Undergr
Burro Mine	San Miguel	Undergr
Bush Canyon	San Miguel	Undergr
C-SR-16A	San Miguel	Surface
Carnation Mine	San Miguel	Undergr
Centennial Mine	San Miguel	Undergr
Cougar Ventures (C-SR-15)	San Miguel	Undergr
Deremo-Snyder	San Miguel	Undergr
Ellison No.1&No.2(C-SR-13)	San Miguel	Surface
Falcon	San Miguel	Undergr
Full Moon Group	San Miguel	Undergr
Full Moon No. 2	San Miguel	Undergr
Hawkeye C-SR-13	San Miguel	Undergr
Ike C-SR-11	San Miguel	Undergr
Pioneer	San Miguel	Undergr
S Hon C-SR-ISA	San Miguel	Undergr
Saint Jude	San Miguel	Undergr
Sears No. 1	San Miguel	Surface
Sego Lily Lou	San Miguel	Undergr
Sitton (C-SR-15A)	San Miguel	Undergr
Summit	San Miguel	Undergr
Suncup No. 2	San Miguel	Undergr

TABLE A-1 (Continued)

<u>Mine Name</u>	<u>County</u>	<u>Mining Method</u>
*** FLORIDA		
Suwannee River	Hamilton	Surface
Swift Creek Mine	Hamilton	Surface
Big Four	Hillsborough	Surface
Florida Agglite Debris Plant	Hillsborough	Surface
Lonesome Mine	Hillsborough	Surface
Bonny Lake	Polk	Surface
Clear Springs	Polk	Surface
Florida Phosphate Corp. Mulberry	Polk	Surface
Fort Green Mine	Polk	Surface
Fort Meade Mine	Polk	Surface
Fort Meade Mine	Polk	Surface
Haines City Mine	Polk	Surface
Haynsworth Mine	Polk	Surface
Hookers Prairie	Polk	Surface
Kingsford Mine	Polk	Surface
Little Payne Creek	Polk	Surface
Nichols Mine	Polk	Surface
Noralyn/Phosphoria Mine	Polk	Surface
Payne Creek-Palmetto	Polk	Surface
Polk County Mine - T/A	Polk	Surface
Rockland Mine	Polk	Surface
Saddle Creek-Ebersbach	Polk	Surface
Silver City Mine	Polk	Surface
South Fort Meade Mine	Polk	Surface
Watson Mine (Swift)	Polk	Surface
*** IDAHO		
Washington Mine	Blaine	Surface
E.A. Rex Uranium and Phosphate	Bonneville	Mineral
Conda Mine	Caribou	Surface
Dairy Syncline	Caribou	Surf-Un
Mabie Canyon	Caribou	Surface
*** MONTANA		
Swamp Frog Mine	Carbon	Surface
*** NEVADA		
Atlanta	Lincoln	Surf-Un
Emerson Mine	Lincoln	Surf-Un

TABLE A-1 (Continued)

<u>Mine Name</u>	<u>County</u>	<u>Mining Method</u>
*** NEW MEXICO		
Ann Lee Mine	McKinley	Undergr
Blue Peak	McKinley	Undergr
Church Rock Mine	McKinley	Undergr
Churchrock No. 1 Mine	McKinley	Undergr
Cobb Nuclear Section 12 Mine	McKinley	Undergr
Dog Flea Mine	McKinley	Surface
Doris Extension	McKinley	Undergr
Haystack Open Pit	McKinley	Surface
Haystack Underground	McKinley	Undergr
Homestake Partners Sec 25 Mine	McKinley	Undergr
Homestake Partners Sec 32 Mine	McKinley	Undergr
Hope Mine	McKinley	Undergr
Johnny M Mine	McKinley	Undergr
Kermac No. 10 Mine	McKinley	Undergr
Kerr-McGee Sec 17 Mine	McKinley	Undergr
Kerr-McGee Sec 19 Mine	McKinley	Undergr
Kerr-McGee Sec 22 Mine	McKinley	Undergr
Kerr-McGee Sec 24 Mine	McKinley	Undergr
Kerr-McGee Sec 29	McKinley	Undergr
Kerr-McGee Sec 30 Mine	McKinley	Undergr
Kerr-McGee Sec 30 West Mine	McKinley	Undergr
Kerr-McGee Sec 33 Mine	McKinley	Undergr
Kerr-McGee Sec 35 Mine	McKinley	Undergr
Kerr-McGee Sec 36 Mine	McKinley	Undergr
Marquez Mine	McKinley	Undergr
Noserock No. 1 Mine	McKinley	Undergr
Poison Canyon	McKinley	Undergr
Ruby No. 1	McKinley	Undergr
Sandstone Mine	McKinley	Undergr
Section 23	McKinley	Undergr
Section 24	McKinley	Undergr
Section 27	McKinley	Undergr
Section 34	McKinley	Undergr
Un Homestake Partners Sec 15 Mine	McKinley	Undergr
United Nuclear Sec 27 East Mine	McKinley	Undergr
Western Section 21	McKinley	Undergr
Rio Puerco Mine	Sandoval	Undergr
Homestake F-33 Mine	Valencia	Undergr
Jackpile Paguate Uranium Pit	Valencia	Surface
Mt Taylor Mine	Valencia	Undergr
P-10 Mine	Valencia	Undergr
P-9-2	Valencia	Undergr

TABLE A-1 (Continued)

<u>Mine Name</u>	<u>County</u>	<u>Mining Method</u>
*** NEW MEXICO (cont.)		
PW-2 and 3	Valencia	Undergr
St. Anthony Open Pit	Valencia	Surface
St. Anthony Strip	Valencia	Surface
*** NORTH CAROLINA		
Pamlico River Deposit	Beaufort	Surface
Texasgulf Inc. Phosphate Complex	Beaufort	Surface
*** SOUTH DAKOTA		
Virginia Mine	Custer	Surface
Darrow #3 Pit	Fall River	Surface
Darrow #4 Pit	Fall River	Surface
Darrow Lease	Fall River	Surface
Heck Lease	Fall River	Surface
Lion #2 Pit	Fall River	Surface
Peterson Lease	Fall River	Surface
*** TEXAS		
Thomas Uranium Pit	Gonzalas	Surface
Beicker Uranium Pit	Kapnes	Surface
Brown Uranium Pit	Kapnes	Surface
Stopletop Uranium Pit	Kapnes	Surface
Weddington Uranium Pit	Kapnes	Surface
Clay West Uranium Plant	Live Oak	In Situ
Smith Uranium Pit	Live Oak	Surface
*** UTAH		
North Wash Pit	Garfield	Undergr
Shoothring	Garfield	Undergr
Cane Creek Mine	Grand	Undergr
Seven Mile Mine-Shinarump 1	Grand	Undergr
Shinarump Mine	Grand	Undergr
State Lease #H066	Grand	Undergr
Wood Mine	Millard	Undergr
Bacardi Cutler Mine	San Juan	Surface
Bacardi Mine	San Juan	Undergr
Beaver Mine (Deer Creek)	San Juan	Undergr
Big Buck	San Juan	Undergr

TABLE A-1 (Continued)

<u>Mine Name</u>	<u>County</u>	<u>Mining Method</u>
*** UTAH (cont.)		
Black Hat Mine	San Juan	Undergr
Bridger Jack Mine	San Juan	Undergr
Columbus Mine	San Juan	Undergr
Cottonwood Group Mines	San Juan	Surface
Far West Incline Mine	San Juan	Undergr
Far West Incline Mine	San Juan	Undergr
Fire-Fly Mine	San Juan	Undergr
Firefly-Pigmy	San Juan	Undergr
Grey Dawn Mine	San Juan	Undergr
Happy Jack Mine	San Juan	Undergr
Humbug Mine	San Juan	Undergr
Lisbon Mine-Pio Algom	San Juan	Undergr
Louise Mine	San Juan	Undergr
Markey Mine	San Juan	Undergr
Mi-Vioa Mine	San Juan	Undergr
North Alice Mine	San Juan	Undergr
Pandora Mine	San Juan	Undergr
Patti Ann Mine	San Juan	Undergr
Pete Lee Lode	San Juan	Undergr
Radium King	San Juan	Undergr
Radium King Mine	San Juan	Undergr
Rattlesnake Dump	San Juan	Surface
School Section 32	San Juan	Undergr
Small Fry Mine	San Juan	Undergr
Smallfry Mine	San Juan	Undergr
Standard Mine	San Juan	Undergr
Standard No. 2	San Juan	Undergr
Vanadium Queen	San Juan	Undergr
Vanadium Queen	San Juan	Undergr
White Canyon No. 1	San Juan	Undergr
Wilson Shaft	San Juan	Undergr
Wilson Shaft	San Juan	Undergr
Yellow Circle Dump	San Juan	Surface
Duffin	Washington	Undergr
Notom Mine	Wayne	Undergr
*** WASHINGTON		
Midnite Mine	Stevens	Surf-Un
Sherwood Mine	Stevens	Surface

TABLE A-1 (Continued)

<u>Mine Name</u>	<u>County</u>	<u>Mining Method</u>
*** WYOMING		
PFTF #17	Campbell	Mineral
Dave Section 10 Pit	Carbon	Undergr
Getty's Oil's Boundary	Carbon	Surface
Overstipping		
North Walker Mine	Carbon	Undergr
Petrotomics Mine	Carbon	Surface
Shirley Basin Mine	Carbon	Surface
South Walker Mine*	Carbon	Undergr
Sullivan Mine*	Carbon	Surface
TSG No. 1 Pit	Carbon	Surface
Anomaly #74 - Kerr McGee	Converse	Undergr
Bear Creek Project	Converse	Surface
Betty Lou Group	Converse	Undergr
Bill Smith Mine	Converse	Undergr
Buffalo Shaft	Converse	Undergr
D-10	Converse	Surface
D-9	Converse	Mineral
Highland Uranium Operation	Converse	Surface
Morton Ranch-No. 1	Converse	Surf-Un
Morton Ranch-No. 2	Converse	Surf-Un
North Morton Mine	Converse	Undergr
Big Eagle Mine	Fremont	Surface
Boundary Overstrip of TFF	Fremont	Surface
Mine-No. 1		
Boundary Overstrip of TFF	Fremont	Surface
Mine-No. 2		
Clyde & Clyde RPFT No. 1	Fremont	Surface
Clyde & Clyde RPFT No. 2	Fremont	Surface
D-6 No. 1	Fremont	Surface
D-6 No. 2	Fremont	Surface
D-6 No. 3	Fremont	Surface
Day No. 26	Fremont	Surface
Federal American Open Pit	Fremont	Surface
Findlay Spring	Fremont	Undergr
Globe Pit	Fremont	Surface
Golden Goose #2	Fremont	Undergr
Golden Goose #4	Fremont	Surface
Golden Goose Mine #1	Fremont	Surface
Hal, Hart, Eagle Mine Group	Fremont	Surface
Loma Mine Group	Fremont	Surface
Loma-Day Claims No. 1	Fremont	Surface
Loma-Day Claims No. 2	Fremont	Surface
Lucky Mc Mine	Fremont	Surface
Lucky Mc Mine Operations	Fremont	Surface
& Maintena		
Lucky Mc Underground	Fremont	Undergr
Operations		

TABLE A-1 (Continued)

<u>Mine Name</u>	<u>County</u>	<u>Mining Method</u>
*** WYOMING (cont.)		
Mine No. 4-A	Fremont	Surface
Mine No. 4-B	Fremont	Surface
P-3 And P-2	Fremont	Undergr
Reserve	Fremont	Undergr
Sec 36 #1	Fremont	Surface
Sec 36 No. 2	Fremont	Surface
Sec 36 No. 3	Fremont	Surface
Seismic #1	Fremont	Surface
Seismic #2	Fremont	Surface
Seismic-Reserve Pit	Fremont	Surface
Sheep Mountain Operations	Fremont	Undergr
Snoball	Fremont	Undergr
Tec Pit	Fremont	Surface
Unknown	Fremont	Undergr
Unknown	Fremont	Undergr
Unknown	Fremont	Undergr
Unnamed	Johnsen	Surface
Hopp No. 1	Matpona	Surface
Hopp No. 2	Matpona	Surface
Pay-Aljob Mine	Matpona	Surface
Star #1	Matpona	Mineral
West Area Pit	Matpona	Surface
Ped Desert Project	Sweetwater	Surf-Un
Sweetwater Uranium Mine	Sweetwater	Undergr

APPENDIX B

REFERENCE URANIUM FUEL FABRICATION FACILITY

Information to characterize the existing contamination, D&D wastes, and recyclable materials from fuel fabrication plants is given in this appendix. This information, based on E180, is used to develop the estimates in Chapter 7.

The process equipment in the various areas of the plant is listed in Table B-1. The equipment is generally categorized by the process areas indicated in Chapter 7 and Figure 7-1. Additional support areas are also included to account for all of the D&D wastes. The emphasis is on major pieces of equipment and items that contribute significantly to D&D wastes; therefore, some items are lumped together under miscellaneous. The amount of residual uranium after final inventory cleanout and initial flushing and cleaning of the process equipment is indicated. The listing of equipment is primarily based on items expected to be contaminated with significant amounts of uranium (roughly 10 grams or more). The uranium is enriched to about 2 to 4% U-235. Additional information and rationale for the assumptions and estimates are given by E180.

Contamination levels prior to decontamination are estimated to be about twice the values given in Table B-1.

The number of duplicate items for the pieces of equipment are indicated and the approximate volume is given in the table. The volumes are based on non-compacted material for the unrestricted waste and on compacted (shipping volumes) for material which will be radioactive LLW. The disposition of the material as unrestricted or restricted LLW is indicated.

The inventory of uranium after decontamination but prior to disassembly, is estimated to 140 kg. Additional decontamination during disassembly of the process equipment and D&D of the facility is estimated to reduce this to about 100 kg contained in 800 m³ of LLW. There is also about 5,300 m³ of material which is not classed as radioactive waste (Table C-1). Much of this material is reusable.

Table C-2 provides a list of the recyclable scrap and reusable material. The items are designated as either recyclable scrap or items which can be reused in their present form. Tanks account for a large fraction of the scrap material.

The information in Tables B-1 and B-2 are used to compile the summary in Table B-3.

Estimates of concrete rubble from decontaminating the buildings are given in Table B-3. This material is not included in Tables B-1 and B-2. The buildings are left standing and are available for unrestricted use.

The material from the waste lagoons is discussed in Chapter 7.

TABLE B-1
PROCESS EQUIPMENT AND D&D WASTES
REFERENCE FUEL FABRICATION FACILITY

Location/Process Area	Equipment	Uranium Inventory After Initial D&D (kg of U)	Relegated to LLW ^a	Volume of Wastes	
				Unrestricted Waste (m ³)	LLW (m ³)
UF ₆ Vaporization Area	Vaporization Chambers (11)	0.65	x	20	99
	Fan Heater Units (11)	0.15	x		22
	Headers and Cold Trap	0.20	x	b	10
	Filter and Duct	2.4	x		
	Ventilation Scrubber	0.05			10
	Misc. (tanks)	—		—	—
Subtotals		3.5		39	180
<u>Chemical Area</u>					
ADU Hydrolysis	Hydrolyzer Tanks (9)	0.7	x		0.6
	HF Scrubber & Filter	0.15	x		3.6
	Misc. (Tanks, Pumps)	0.20	+		
Precipitation Digestion	Precipitation Tanks (8)	0.05	+		
	Digestion Tanks	0.02	+		
	Misc.	0.08	+		
Centrifuging	Centrifuge (10)	0.10	+		
	Misc. (Ducts, Tanks, Pumps)	0.20	+		
Calcining	Calciners (6)	11	40%		
	Duct and Hoods	9			
Milling	Mill, etc.	7.8			
Pelletizing	Slug Press	10	+	34	c
	Misc. (Duct & Hood)	9.4			
Granulation	Granulators (6)	8.0	x	23	7
	Misc.	6.0			

- a An "x" indicates that most of the material is disposed of as LLW. A "+" indicates that essentially all the material is decontaminated for unrestricted use or waste. Percent values indicate the percent of the volume that remains as LLW after final decontamination.
- b For simplicity, only values that contribute a significant fraction of the total are entered. The subtotals include all contributions, not just the summation of values in the table.
- c Hyphens (-) indicate insignificant values.

TABLE B-1 (Continued)

PROCESS EQUIPMENT AND D&D WASTES
REFERENCE FUEL FABRICATION FACILITY

<u>Location/Process</u>	<u>Equipment</u>	Uranium Inventory After Initial D&D (kg of U)	Relegated to LLW	<u>Volume of Wastes</u>	
				<u>Unrestricted Waste (m³)</u>	<u>LLW (m³)</u>
Bucket Loaders	Loaders (6)	0.5	x	22	8
	Bins and Conveyors (6)	0.3			
Reduction	Flame Reactors (4)	2.0	x	5	2
	Misc.	1.9			
	Scrubber Demister	-	x		6
Uranium Puri- fication	Misc. Equipment	<u>2.1</u>		—	—
Subtotal for Chemical Area ^b		70		580	200
<u>Powder Room</u>	Blender	1.3	+		
	Roller Conveyor	-	+	26	
	Misc. (Hood, etc.)	<u>0.3</u>		—	—
Subtotal ^b		1.6		54	9
<u>Pelletizing Room</u>	Presses (14)	0.8	+	100	
	Blending Station	1.2	+		
	Slugger	1.2	+		
	Granulator and Equipment	20	+		
	Hoods and Ducts (4)	<u>19</u>	+	—	—
Subtotal		42		130	23
<u>Pellet Sintering</u>	Sintering Furnaces	0.15	30%	130	55
	Hoods and Ducts	0.55	+		
	Misc. Equipment	<u>0.09</u>	+	—	—
Subtotal		0.8		230	59
<u>Pellet Grinding</u>	Grinders	2.0	+	6	
	Hood and Ducts	1.60	+		
	Feed Station	0.20	+		
	Carts and Cabinets	-	+	89	
	Misc.	<u>0.6</u>		—	—
Subtotal		4.4		130	5.3

TABLE B-1 (Continued)

PROCESS EQUIPMENT AND D&D WASTES
REFERENCE FUEL FABRICATION FACILITY

<u>Location/Process</u>	<u>Equipment</u>	Uranium	Relegated	<u>Volume of Wastes</u>	
		Inventory After Initial D&D (kg of U)		to LLW	Unrestricted Waste (m ³)
<u>Rodding Room</u>					
Rod Loading	Rod Loading Station	0.05	+	19	
	Misc. Equipment	0.05	+		
	Hood, Duct, and Filters	0.04	+		
	Rod Handling Boxes (600)	-	+	99	
Rod Outgassing	Furnaces	0.10	+	43	
	Misc. (Filter and Ducts)	0.10	+		
Rod Closure	Welders and Accessories	-	+	18	
	Inspection	-	+	10	
	Filters and Ducts	0.05	+		
Subtotal		0.75		290	0
<u>Gadolinia Rod Fabrication</u>					
	Powder Glovebox	1.3	x		0.9
	Blender Glovebox	0.6	x		1.0
	Other Gloveboxes (2)	0.2	x		2.8
	Pellet Press	0.9	x		2.7
	Sintering Furnace	0.15	x		4.5
	Grinder	0.35	x		2.7
	Rod Loader	0.05	+	6.9	
	Rod Closer	-		18	
	Hoods, Ducts, Filters	1.15			
	Misc. (Cabinets, etc.)	0.05	+	25	
Subtotal		4.7		76	18
<u>Uranium Scrap Recovery</u>					
	Crusher Grinder	0.50	x		2.3
	Mixer	0.10	x		2.0
	Rod Cutoff	-	x		2.3
	Bucket Unloader	0.05	x		1.0
	Furnace	-	x		13
	Misc.	0.05	x		
	Hoods and Ducts (5)	0.7	x		
Subtotal		1.4		5	27

TABLE B-1 (Continued)

PROCESS EQUIPMENT AND D&D WASTES
REFERENCE FUEL FABRICATION FACILITY

<u>Location/Process</u>	<u>Equipment</u>	Uranium Inventory After Initial D&D (kg of U)	Relegated to LLW	<u>Volume of Wastes</u>	
				Unrestricted Waste (m ³)	LLW (m ³)
<u>Support Laboratories</u>					
Analytical Lab	Hoods and Ducts	0.30	x		
	Misc. Equipment	0.30	+		
Process Development Lab	Blenders	0.35	+		
	Sintering Furnace	0.20			
	Reactors	0.15	x		10
	Rod Development Equipment	0.10			
	Hoods and Ducts	0.65			
Hot Maintenance Shop	Misc. Equipment	0.60	+		
	Filter Vents and Ducts	0.70	+		
Hot Instrument Shop	Equipment	0.10	+		
	Hood and Duct	<u>0.10</u>	+		
Subtotal (Labs and Maintenance)		3.6		420	41
<u>Radwaste Processing</u>	Tanks (2)	0.20	+	130	
	Hoods and Duct	0.05	+		
	Centrifuge	0.05	+	1.7	
	Misc. Equipment	0.05	+		
<u>Decontamination Facility</u>	Misc. Equipment	<u>0.45</u>	+	<u>20</u>	<u>0</u>
Subtotal (Radwaste and Decon.)		0.8		160	0
<u>Laundry</u>	Washers and Driers (2)	-	X		20
	HEPA Filters (2)	-	X	1.1	1.1
	Misc. Tables, etc.	-	+	<u>6</u>	<u>-</u>
Subtotal				7	21
<u>Change Rooms</u>	Monitoring Equipment	-	+	3.7	-
	Misc.		+	<u>3.8</u>	<u>-</u>
Subtotal				7.5	

TABLE B-1 (Continued)

PROCESS EQUIPMENT AND D&D WASTES
REFERENCE FUEL FABRICATION FACILITY

Location/Process	Equipment	Uranium Inventory After Initial D&D (kg of U)	Relegated to LLW	Volume of Wastes	
				Unrestricted Waste (m ³)	LLW (m ³)
<u>Incinerator</u>	U Scanners		+	3.6	
	Packaging Equipment		+	3.6	
	Shredder		x	-	4.1
	Vortex Chamber & Incinerator	2.0	x	-	14.5
	Scrubbers and Accessories	1.7	x		5
	Misc.	<u>4.3</u>			
Subtotal		8.0		19	26
<u>HEPA Filter Rooms</u>	Filter and Ducts	0.3	+	0	0
<u>Fluoride Waste Treatment Area</u>	Asphalt & Other Pond Liners		x		50
	(4)		x		15
	Pumps & Valves		+		
	Tanks	0.30		1050	
	Centrifuge	0.40			
	Equipment	<u>0.05</u>			
Subtotal (Fluoride Waste Treatment)		0.75		1700	100
<u>Nitrate Waste Treatment</u>	Tanks	0.25	+	410	-
	Centrifuge	0.10	+	8	-
	Misc. (Including Pond Liner)	-	x		<u>10</u>
Subtotal		0.35		460	10
<u>Radwaste Effluent Treatment</u>	Pumps & Valves				
	Misc. (Soil, Valves, Pumps)		x	23	5
	Pond Liners (30)		x		<u>32</u>
Subtotal				57	40
<u>Powder Warehouse</u>	Storage Racks		+	170	-
	Forklift (20)		+	12	-
	Misc.		+	<u>28</u>	-
Subtotal				210	
<u>Uranium Storage Pads</u>			+	0	0

TABLE B-1 (Continued)

PROCESS EQUIPMENT AND D&D WASTES
REFERENCE FUEL FABRICATION FACILITY

<u>Location/Process</u>	<u>Equipment</u>	Uranium Inventory After Initial D&D (kg of U)	Relegated to LLW	<u>Volume of Wastes</u>	
				Unrestricted Waste (m ³)	LLW (m ³)
<u>UF₆ Cylinder</u>	Storage Racks		+	150	-
<u>Storage</u>	Misc.		+	<u>18</u>	<u>-</u>
Subtotal				170	0
<u>Other</u>	Misc. Material		+	183	0
	Excess Equipment			<u>320</u>	<u>35</u>
Subtotal				503	35
<u>Waste Treatment</u>	Misc. (Tanks)		+	65	10
<u>Building</u>					
TOTALS ^b		140		5300	800

TABLE B-2
REUSABLE MATERIALS, REFERENCE FUEL FABRICATION FACILITY
Source: E180

<u>Process Area</u>	<u>Equipment</u>	<u>Volume (m³)</u>	<u>Disposition</u>	
			<u>Recycled Scrap</u>	<u>Reuse</u>
UF ₆ Vaporization Area	Operator Platform	20	x	
	Quarantine Tanks	17	x	
Chemical Area	Tanks (46)	70	x	
Powder Storage	Roller Conveyor	26	x	
Pelletizing Room	Scales and Balances (14)	7.1		x
Sintering Room	Scales (5)	2.6		x
	Sintering Boats (600)	9.3		x
	Pellet Sampling and Measuring Station	6.8		x
	Misc. (Consoles, Carts)	76	x	
Grinding Room	Pellet Tray Cabinets	45		x
	Scales & Inspection Equipment	12		x
	Misc. (Carts, HEPA units)	37	x	
Rod Loading Room	Transfer Carts (9)	20		x
	Rod Handling Boxes (600)	89	x	
	End Plug Cutoff Lathe	1		x
	Cladding and Component Storage Rack	8.9		x
	Scales	1.0		x
Rod Outgassing	Vacuum Furnaces (3)	43		x
	Vacuum Pumps, etc.	20		x
	Control Console	9		x
	Misc.	3	x	
Rod Closure	Welders and Associated Equipment	18		x
	Lathe	1.0		x
	Inspection Station	10		x
	Misc.	2	x	
Gadolinia Facility	Storage Cabinets and Tables	25		x
	Rod Closure Welder	18		x
	Misc.	2		x

TABLE B-2 (Continued)

REUSABLE MATERIALS, REFERENCE FUEL FABRICATION FACILITY
Source; E180

<u>Process Area</u>	<u>Equipment</u>	<u>Volume (m³)</u>	<u>Disposition</u>	
			<u>Recycled Scrap</u>	<u>Reuse</u>
Uranium Scrap Recovery	Scales (2)	2		x
Analytical Laboratory	Laboratory Equipment Including Emission Spectrometer	100		x
Process Development Lab	Blending Equipment	3		x
	Sintering Equipment	40		x
Hot Maintenance Lab	Machine Shop Equipment	54		x
	Benches and Cabinets	20		x
	Tool Cabinets	6.4		x
Hot Instrument Shop	Electronic Test Instrument	1.5		x
	Benches & Cabinets	25		x
Decontamination Facility	Decon Spray Booth	6.8		x
	Sinks and Tables	5.5		x
	Misc. Equipment	5		x
	Radiation & U Scanner (restricted reuse)	1.8		x
Subtotal		19		x
Laundry Room	Tables	2.3		x
Change Rooms	Monitors	3.7		x
	Misc.	3.8		x
Incinerator	U Scanners	3.6		x
	Packaging Equipment	3.6		x
Nitrate Waste Treatment	Tanks (3)	410		x
	Centrifuge	8		
Fluoride Waste Treatment	Centrifuge	8		x
	Tanks	700	x	
Powder Warehouse	Storage Racks	170		x
	Forklift	12		x
UF ₆ Cylinder Storage	Storage Racks	153		x
	Scales	2		x

TABLE B-3

ESTIMATED SOURCES OF CONCRETE RUBBLE FROM D&D
REFERENCE FUEL FABRICATION FACILITY

Source: E180

<u>Location</u>	<u>Estimated Percent of Area Removed</u>	<u>Volume Removed^a (m³)</u>
<u>Fuel Manufacturing Building</u>		
Vaporization	5	0.5
Chemical and Powder Processing	4	4.3
Powder Storage and Feed	3	0.7
Pelletizing	2	0.4
Sintering	1	0.3
Grinding	1	0.1
Incinerator Facility	2	0.2
Remainder of Building	0.4	1.3
<u>Outside Fuel Manufacturing Building</u>		
Fluoride Waste Treatment	- ^b	3.2
Nitrate Waste Treatment	-	2.1
Waste Treatment Building	-	1.2
Equipment Storage Pads	-	1.0
Uranium Storage Pads	-	0.4
Radwaste Treatment	-	3.0
Remainder of Site	-	1.0
TOTALS (Rounded off)		20

a. Based on removing an average depth of 5 m. The shipping volume is twice the volume of the rubble.

b. A dash indicates that this information is not applicable.

APPENDIX C

REFERENCE URANIUM HEXAFLUORIDE CONVERSION FACILITY

Information to characterize the existing contamination and D&D wastes from uranium hexafluoride conversion plants is given in this appendix. This information is used in Chapter 5.

C.1 PROCESS EQUIPMENT

The process equipment in the reference uranium hexafluoride conversion plant is identified in Table C-1. The process categories are the same as those identified and described in Chapter 5, and Figure 5-1. The major pieces of equipment for each process are listed and estimates are given for the contaminated surface area, the shipping volume and the residual uranium after the final inventory cleanout. The residual inventory of uranium after flushing the system with a decontaminating solution and removing some surface contamination is also given. Final inventory cleanout is part of the plant operating procedures and not a D&D function. Furthermore, the wastes generated from final inventory cleanout and the initial decontamination are processed through the plant's waste systems. The uranium is recovered and the wastes are incinerated or condensed. Consequently, they only make a minor contribution to the D&D wastes.

The next phase of D&D is disassembling the equipment and additional decontamination. The column on the right in Table C-1 designates what equipment is decontaminated sufficiently for release for unrestricted waste or scrap and which equipment is designated for LLW disposal at a licensed site. Subtotals for the process categories indicate the volume of LLW and

TABLE C-1

EXISTING CONTAMINATION AND D&D WASTES FROM A URANIUM CONVERSION FACILITY^a
Source: E181

	Estimated Inventory of U				
	Contaminated Surface Area (m ²)	Shipping Volume (m ³)	After Operational Cleanout ^c (kg)	After Decontamination ^c (kg)	Material Disposed Of As LLW ^b
Location/Equipment					
<u>Sampling Station & Feed Receiving</u>					
Drum Elevator(2) ^d	37.0	13	5	2.5	X
Yellowcake Receiving Bin(2)	37.5	13	50	25	+
Primary Sampler I	8.1	2.7	10	5	X
Primary Sampler II	8.1	2.7	10	5	X
Secondary Sampler	7.5	2.5	10	5	X
Yellowcake Transfer Screw	12.6	4.2	40	20	X
Bucket Elevator	18.4	4.8	25	12.5	X
Digest Feed Bin	8.8	2.6	50	25	X
Piping	20.0	2.6	5	2.5	+
Hood and Ductwork	12.3	4.1	10	5	30%
ADU Storage Tank(2)	-- ^e	76	-- ^e	-- ^e	+
Receiving & Weight Tank	--	3.8	--	--	+
Receiving Pumps(2)	--	3.0	--	--	X
Transfer Pumps(2)	--	2.8	--	--	X
Misc. Equipment	--	2.0	--	--	X
UF ₄ Feed Hopper	--	12			X
UF ₄ Dump Hopper	--	3.0			X
UF ₄ Digestion Tank(2)	--	17			+
Scrubber System(2)	--	6.8			X
Pumps(2)	--	2.3			X
Subtotal of All Wastes		180	220	110	
Subtotal for LLW ^f		66		77	

a This table is a composite of information from Tables C.3-1, A.2-1 to 1.2-9, and G.2-1 to G.2-14 from E181.

b An "X" designates material (after the initial decontamination) that cannot be decontaminated and that is disposed of as radioactive LLW. If part of an item is decontaminated, and part disposed of as LLW, the percentage disposed of as LLW is indicated. A "+" indicates the item is decontaminated and disposed of as commercial waste.

c The uranium from the initial contamination (i.e., the difference between Columns 4 and 5) is recovered by processing the wastes through the radwaste system.

d The number in parenthesis indicates the number of units if there is more than one.

e Values not available, probably insignificant.

f Subtotal of wastes designated as LLW.

TABLE C-1 Continued

Estimated Inventory of U					
Location/Equipment	Contaminated Surface Area (m ²)	Shipping Volume (m ³)	After Operational Cleanout ^c (kg)	After Decontamination ^c (kg)	Material Disposed Of As LLW ^b
<u>Uranium Dissolution and Solvent Extraction</u>					
Digestors(3)	132.0	44	700	350	+
Adjustment Tanks(2)	90.0	30	100	50	+
Pumper Decanters(6)	42.0	14	50	25	X
Scrub Decanter(2)	12.9	4.3	60	30	X
Re-extraction Pulse Column(2)	7.5	2.5	90	45	X
Extraction Waste Holding Tanks(3)	108.0	36	100	50	+
Piping	19.2	11	10	5	+
Miscellaneous Equipment	--	5	--	--	+
Subtotal of All Wastes		150	1100	550	
Subtotal for LLW ^f		21		100	
<u>Uranyl Nitrate Concentration</u>					
Evaporator	24.0	7.9	1000	500	X
Boiling Tanks(3)	126.0	42	500	250	+
Filter(3)	3.5	1.5	100	50	X
Piping	10.2	3.4	5	2.5	+
Hood and Ductwork	18.9	6.3	5	2.5	50%
Miscellaneous Equipment	--	0.9	--	--	X
Subtotal of All Wastes		62	1600	800	
Subtotal for LLW ^f		13		550	
<u>Denitration</u>					
Denitrator(4)	81.6	27	300	150	X
Denitrator Scrubber Cooler(4)	24.0	2.0	600	300	X
Cooling Screw(4)	16.2	5.4	20	10	X
UO ₃ Vertical Elevator(2)	12.9	4.3	30	15	X
Pulverizer and Surge Bin(2)	57.0	35	150	75	50%
Piping	60.0	6.8	5	2.5	+
Hoods and Ductwork	150.0	7.4	5	2.5	+
Miscellaneous Equipment	--	1.5	--	--	X
Subtotal of All Wastes		89	1100	550	
Subtotal for LLW ^f		58		510	

TABLE C-1 Continued

Location/Equipment	Estimated Inventory of U				Material Disposed Of As LLW ^b
	Contaminated Surface Area (m ²)	Shipping Volume (m ³)	After Operational Cleanout ^c (kg)	After Decontamination ^c (kg)	
<u>Reduction of UO₃ to UO₂</u>					
UO ₃ Storage Bin(2)	205.2	68	50	20	+
Reduction Fluid Bed(4)	102.0	34	300	150	X
Piping	60.0	20	40	20	+
Hoods and Ductwork	120.0	50	20	10	+
Miscellaneous Equipment	--	35	--	--	X
Subtotal of All Wastes		210	410	200	
Subtotal for LLW ^f		70		150	
<u>Hydrofluorinator</u>					
UO ₂ Filter Bin(4)	73.5	25	100	50	+
1st Stage					
Hydrofluorination(4)	48.9	16	800	400	30%
2nd Stage Hydrofluorination					
Fluid Bed(4)	48.9	16	600	300	30%
UF ₄ Seal Hopper(4)	32.4	11	40	20	X
UF ₄ - UO ₄ Intermediate					
Seal Hopper(4)	32.4	11	40	20	X
UF ₄ Purge Conveyor(4)	15.6	5.2	20	10	X
Redler Conveyor 509(4)	15.2	5.2	20	10	X
UF ₄ Storage Hopper(4)	32.4	10.8	400	200	40%
Redler Conveyor 510(4)	15.6	5.2	80	40	40%
Screw Feeder(4)	--	20	--	--	40%
Piping	13.8	4.6	5	2	--
Subtotal of All Wastes		130	2100	1100	
Subtotal for LLW ^f		69		350	
<u>Fluorinator</u>					
Primary Fluorination(5)	108.3	36	800	400	60%
Redler Conveyor(2)	7.5	2.5	20	10	X
Primary Filter(4)	36.6	12	60	30	X
Primary Cold Trap(6)	181.5	61	110	55	X
Product Cylinder(2)	103.2	34	70	35	X
Backup Filter(2)	7.2	2.4	80	40	X
Cleanup Reactor Feed					
Hopper(2)	15.6	5.2	100	50	X
Cleanup Reactor(2)	43.8	15	500	300	X
Redler Conveyor 512(2)	7.5	2.5	20	10	30%
Backup Filter(2)	7.2	2.4	500	250	40%
Secondary Cold Trap(4)	77.1	26	200	100	X
Piping	66.0	22	5	2.5	--
Hoods and Ductwork	19.4	6.8	5	2.5	--
Subtotal of All Wastes		230	2600	1300	
Subtotal for LLW ^f		180		960	
<u>TOTAL OF ALL WASTES</u>					
TOTAL FOR LLW ^f		1050	9100	4600	
		480		2700	

the kilograms of uranium remaining in or on that waste. All of this information is based on E181.

The inventory estimates in Table C-1 assume that the decontamination after final inventory cleanout reduces the amount of uranium in the process equipment by a factor of two. The amount of uranium in process equipment that goes to LLW is reduced by almost an additional factor of two during the disassembly and decontamination associated with D&D.

The reduction for the uranium going to LLW versus the inventory after initial decontaminating only takes credit for uranium removed from equipment which is decontaminated sufficiently to allow recycle or unrestricted waste disposal (see Table C-1). The calculations in Table C-1 do not include uranium removed in attempts which are unsuccessful in decontaminating equipment and allowing its unrestricted release. This results in a conservatively high waste estimate. However, when initial decontamination efforts are unsuccessful it will probably be cost effective to concede that certain items are not worth additional efforts for decontamination. It should be noted that E181 includes an additional factor of two reduction for uranium removal during decontamination efforts; this factor is not interjected into these estimates.

C.2 SUPPORT FACILITIES

Estimates of D&D wastes from some of the major support areas of the facility are given in Table C-2. The relative quantity of uranium remaining on this equipment is small, and is not specifically listed.

The following items summarize the D&D waste estimates for additional

TABLE C-2

ESTIMATES OF VOLUMES OF D&D WASTES FROM SUPPORT FACILITIES OF URANIUM CONVERSION PLANT
Source: E181^a

<u>Location/Equipment</u>	<u>Designation of Waste</u>		
	<u>Shipping Volume (m³)</u>	<u>Material Disposed of as LLW^b</u>	<u>Non-Radioactive Waste^c</u>
<u>Analytical Laboratory</u>	62		X
Subtotal of All Wastes	62		
Subtotal for LLW	0		
<u>Nitric Acid Recovery</u>			
Tanks(2)	8.0		X
Scrubbers(2)	8.0	X	
Acid Absorbers(2)	1	X	
Pumps(2)	4.7	X	
Piping	6.4		X
Miscellaneous Equipment	3.2	X	
Subtotal of All Wastes	31		
Subtotal for LLW	17		
<u>Temporary Radioactive Waste Room</u>			
Quarantine Tank	81	X	
Slab Tanks	49	X	
Centrifuge	1.7	X	
Miscellaneous Clean Equipment	100		X
Miscellaneous Equipment (Pumps, etc.)	3.6	X	
Subtotal of All Wastes	240		
Subtotal for LLW	140		

TABLE C-2 (Continued)

<u>Location/Equipment</u>	<u>Shipping Volume (m²)</u>	<u>Designation of Waste</u>	
		<u>Material Disposed of as LLW^b</u>	<u>Non-Radioactive Waste^c</u>
<u>Decontamination Facility</u>			
Spray Booth	7		
Cleaning Sinks & Tables	6		
Miscellaneous Equipment	5		
Radiation and U Scanner	2		
Subtotal of All Equipment	20	all excessed to appropriate use.	
<u>Fluoride Generation Area</u>			
Waste Gas Burners	23	40% ^b	X
Fluoride Cells(60)	160	X	
Fluoride Surge Tank(2)	18	40% ^b	X
Fluoride Filters(4)	4	X	
HF Condensers(2)	13	30% ^b	X
Miscellaneous Contaminated Equipment	8		
Miscellaneous Clean Equipment	50		
Subtotal of All Wastes	280		
Subtotal for LLW	190		
<u>Incinerator Facility</u>			
Input and Output U Sanners(2)	3.6		X
Packaging Equipment	3.6		X
Shredder and Incinerator Chamber	19	X	
Offgas Scrubber and Tank	5.0	X	
Miscellaneous Equipment	13	X	
Subtotal of All Wastes	44		
Subtotal for LLW	37		

a The information is taken from E181, Tables G.2-3, G.2-9, G.2-13, A.2-11, A.2-12, A.2-13, A.2-14, and A.2-15, and Section G, supplemented by information from Table H.2-2.

b Material designated as "X" is disposed of as LLW. A percentage indicates the percent of material disposed as LLW.

c Material is released for unrestricted use.

Table C-3. Waste volumes from pipe and ducts included in specific processes have been included in Table C-1. These wastes are allotted to the previously designated process categories. Estimates of volumes of unrestricted waste and restricted radioactive LLW are given.

TABLE C-3
D&D WASTES FROM PIPING, VENTILATION, AND CONCRETE RUBBLE
FROM THE REFERENCE URANIUM CONVERSION FACILITY
Source: E181a

Location or Process	Ancillary Equipment			Category and Volume of Waste			Concrete Rubble	
	Piping And Conduit (m ³)	Ducts And Supports (m ³)	Trays And Light Fixtures (m ³)	Unrestricted Waste (m ³)	Restricted Waste LLW (m ³)	Floor Area (m ²)	Restricted Waste LLW (m ³)	
Sampling Station and Feed Receiving	36	63	9	94	14	420	15	
Dissolution and Solvent Extraction	56	128	--b	118	66	577	38	
Uranyl Nitrate Concentration	8	109	20	75	62	130	6	
Denitration	10	50	13	50	23	130	6	
Reduction(UO ₃ to UO ₂) and Hydrofluorination	8	51	11	--	70	530	20	
Fluorination	--	--	--	--	--	270	7	
Analytical Laboratory	4	61	11	72	4	175	5	
UF ₆ Cylinder Loading	1	19	3	21	2	130	3	
Other Support Areas	3	42	7	42	10	--	--	
TOTAL (Rounded Off)	130	520	74	470	250	2400	100	

a Taken from E181, Tables A.2-19, H.2-2, and H.2-3. Minor changes were made to make values compatible.

b Minor contribution or values not known.

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